PERFORMANCE EVALUATION OF TWO WSN GENERATIONS IN REAL ENVIRONMENTS

BY

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I dedicate this thesis to my parents,

I could never have done this without your faith, support, and constant encouragement. Thank you for teaching me to believe in myself, in God, and in my dreams.

I also dedicate this work to my brilliant and outrageously loving and supportive wife, our exuberant, sweet, and kind-hearted little girls, Hams & Ruba.

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LIST OF ABBREVIATIONS

ADC	Analog to Digital Converter
CD	Compact Disc
CPU	Central Processing Unit
dBm	Decibel milliwatts
DMI	Data Message Interval
DSP	Digital Signal Processor
GUI	Graphical User Interface
HP	High Power
IEEE	Institute of Electrical and Electronics Engineers
LP	Low Power
MDA	Monochrome Display Adapter
MEMSIC	Micro Electro Mechanical Systems Investment Company
MHz	Mega Hertz
MIB	Management Information Base
MTS	Maine Technical Source
MULE	Mobile Ubiquitous LAN Extensions
ODBC	Open Data Base Connectivity
PC	Personal Computer
PIR	Passive Infrared Sensors
PLC	Packet Loss Consideration
PM	Post Meridiem
RAM	Random Access Memory
RF	Radio Frequency

RSS	Radio Signal Strength
SQL	Structured Query Language
USB	Universal Serial Bus
V	Voltage
WSN	Wireless Sensor Network
ZC	ZigBee Coordinator
ZR	ZigBee Routers

ABSTRACT

Full Name : Mohammed Saleh Habtoor

Thesis Title : PERFORMANCE EVALUATION OF TWO WSN GENERATIONS IN RE-AL ENVIRONMENTS

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Wireless sensor network (WSN) technology has spread quickly into several fields. This technology has come to the forefront of the scientific community recently. The usage of these sensors and the opportunity of organizing them into networks have exposed some research issues and have highlighted different ways to deal with certain problems. In this work we aim at conducting a study of the performance of two generations of wireless motes (IRIS and LOTUS), in terms of communications, in different scenarios and environments. This study will help decision makers in choosing the appropriate sensor for their specific application and requirement.

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ملخص الرسالة

الاسم الكامل: محمد صالح مهدي حبتور

عنوان الرسالة: تقييم أداء نوعين من المستشعرات اللاسلكية في بيئات عمل حقيقية

التخصص: شبكات كمبيوتر

تاريخ الدرجة العلمية: رجب 1435 هجرية

اصبحت تكنولوجيا المستشعرات اللاسلكية واحدة من اهم واسرع التقنيات انتشاراً في شتى المجالات. هذا الانتشار الكبير لأستخدامات المستشعرات اللاسلكية تسبب بأهتمام واسع في الاوساط العلمية بهذه التكنولوجيا. ان الاستخدامات المتعددة والمجالات المختلفة لاستخدام هذه التكنولوجيا كانت ولا زالت محط بحث واستقصاء من قبل الباحثين والدارسين في مجال التكنولوجيا، حيث ظهرت ابحاث كثيرة لتطبيقات متنوعة من شانها تسخير هذه التقنية لخدمة البشرية. من هذه الابحاث ظهرت امكانية استخدام هذه المستشعرات للعمل كشبكة لاسلكية واحدة تقدم مجموعة من البيانات القيمة التي يمكن استخدامها لاغراض اخرى. هناك الكثير من الانواع منتشرة هذه الايام في الاسواق وكل نوع يدعي انه الافضل اداءً مما قد يؤدي الى اختيار خاطئ لنوع معين لايخدم الهدف المراد. في هذه الدراسة، سنتعرف على نوعين من هذه المستشعرات اللاسلكية وهما IRIS و LOTUS حيث سنقوم بأجراء مجموعة من التجارب العملية الميدانية للتعرف على مدى كفاءة كل نوع على حده. هذه الدراسة ستقدم معلومات قيمة لصانعي القرار لكي يتم اختيار المستشعر الافضل بكل سهولة وفقاً للنتائج التي ستقدمها هذه الدراسة.

درجة الماجستير في العلوم

جامعة الملك فهد للبترول والمعادن

الظهران, المملكة العربية السعودية

رجب ١٤٣٥

CHAPTER 1

INTRODUCTION

1.1 Background

A wireless sensor network (WSN) is a set of nodes that form a cooperative network [1,12]. Every node can do processing tasks with one or more microcontrollers, CPUs or DSP chips. Every node has an RF transceiver with a single omnidirectional antenna. It is equipped with a power source, such as batteries or solar cells. The nodes often self-organize after being deployed in an ad hoc fashion and communicate wirelessly.

At this time, wireless sensor networks are beginning to be spread dramatically. It is easy to say that over the next few years wireless sensor networks will cover the world with access to them through the Internet. This new technology can be used in various multidisciplinary fields including environmental monitoring, military, medical, entertainment, transportation, homeland defense, crisis management, and smart spaces. [1, 13]

We can classify WSNs applications into two categories: (1) tracking and (2) monitoring [25, 17, and 29] (see Fig. 1). Tracking applications include tracking humans, animals, vehicles, and objects. Monitoring applications include health and wellness monitoring, indoor/outdoor environmental monitoring, power monitoring, inventory location monitoring, seismic and structural monitoring, and factory and process automation.

Existing WSNs are used on land, underground, and underwater [25]. This new technology faces some challenges and constraints that vary depending on the environment in which the network deployed. Many of these challenges are in terms of communication which impacts the performance of the network.

In the daily life, there are many applications rely on sensor networks (wired and wireless) that we can see around us everywhere. For example, in KFUPM, we have surveillance cameras, fire and temperature sensors, and even light switches controlled by Passive Infra-red Sensors (PIR) sensors.

In this work, we evaluate the communication performance of IRIS and LOTUS motes. In our study, we will use Radio Signal Strength (RSS) as an indicator for the quality of com-munication as many studies used it as we will see later in similar studies. We also consider the packet drop rates and the packet arrivals to evaluate the performance of multi hops networks.

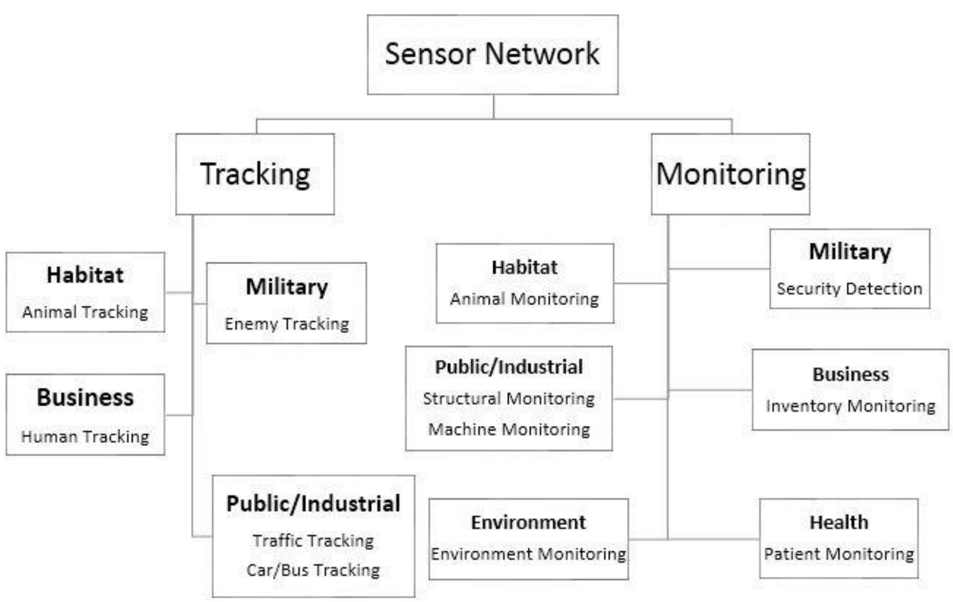


Figure 1 WSN Applications

1.2 Motivation

There are some non-favorable factors that we must consider when implementing WSN on a real test environment such as, difficulty of implementation, time-consuming, hardware failure, and financial investment, etc [2, 10].The choice of appropriate equipment and devices to achieve a task is one of the most important factors that ensures its success. When we build a new wireless sensor network, we have to select the best motes to ensure that our application will work excellently. Nowadays, MEMSIC provides a variety of motes and sensors that can be used anywhere to provide advanced monitoring, automation and control solutions for a range of industries. LOTUS, IRIS, MICAz / MICA2, TelosB and Cricket are motes produced by MEMSIC with some slight differences and additions for each type. The problem that we want to address in this study is how to choose the most appropriate motes for different scenarios and environments. To the best of our knowledge, this is the first study conducted in order to evaluate the performance of IRIS and LOTUS wireless sensor motes in real environment.

1.3 Research Objective

We are not aware of any research that evaluate the performance of these motes in real environment where such evaluation will provide valuable information for decision makers in order to choose the best type of sensors for a specific application. Based on the above, we would like through this research to provide a comprehensive comparison between two generations of wireless sensor network systems which are IRIS and LOTUS. Our study will focus on evaluate the performance in terms of communication in different scenarios and environments.

1.4 Organization of Thesis

This thesis is organized as follows:

Chapter 1 contains a brief introduction that provides an overview of the concept, characteristics, application areas and the technologies of wireless sensor network.

Chapter 2 covers preliminary the literature review in which similar studies and related works will be described.

Chapter 3 introduces the hardware and the software requirements for this research for both IRIS and LOTUS wireless motes.

Chapter 4 explains what the experiment design principle and experiment scenarios are. This chapter also deals with the practical issues like, setting up the test-bed and implementing of the experiment.

Chapter 5 provides a detailed explanation about the experiments, also reviewed the analyzed results.

Chapter 6 concludes this thesis by summarizing our work and recommendations, as well as discuss the suggestions for future works.

CHAPTER 2

LITERATURE REVIEW

In this chapter we look at similar studies that used WSNs technology to practically provide innovative and alternative solutions. We will focus on the factors that we are going to use in this study which are Received Signal Strength Indicator (RSSI), Packet drops and Packet Arrivals. A more comprehensive overview of the WSNs can be found in [19, 30].

2.1 Radio Signal Strength

Radio signal strength (RSS) is used in many applications such as military and robotics for range estimation. In order to estimate the distance between two nodes, the received signal strength from the sender is measured and find the equivalent distance. RSSI is defined voltage in the received signal strength indicator (RSSI) pin on radio signal. The main problem of RSSI is its high sensitivity to environmental changes. The impacts of the surroundings on RSSI can be large, especially in more complex environments where reflections and obstructions are usually very high [18].

Many studies have been done regarding to RSSI in order to determine its accuracy and consistency for many applications. The majority of these studies are focuses on the factors that may affect the signal strength on the way to its destination. Thus, such factors may adversely affect the strength of the signal and its behavior which leads to other problems that may cause a failure in the whole system

There is no clear correlation between signal strength and distance as reported in [27], especially for the indoor environment where the walls, metal furniture and electronic interference can create a great effect on signal strength behavior.

A Study showed that signals on its way can take multiple paths and hit some obstacles, therefore signal strength changes depending on the angle at which signals hit the obstructions [21]. Two types of signals arises due to hitting on obstruction, transmitted and reflected signal [21]. In this research, we aim to find the effects of both obstructions and reflections in a more complicated closed and open environments in order to know which WSNs generation is better to use in those environments.

2.2 Similar Studies

Kshitij Shinghal et. al [16] reported that WSN nodes can operate with high efficiency to collect data of soil, such as compaction and fertility, biomass yield, crop yield, local climate data, etc. In their study, they use WSN nodes to improve yield and save water by irrigation scheduling. By using WSN irrigation management can guarantee a healthier crop yield and increases the application efficiency of irrigation system by 10 % [16] [5]. Fig.2 show the general architecture of this system where that system consists of four main components which are as follows: the wireless transceiver unit, the processing unit, the sensing unit and finally the power unit. In short, each unit has a specific task to do in this system. The physical quantities such as humidity, pressure, temperature are measured by the sensing unit and thereafter the processing unit manages the communication protocols that used between nodes. The transceiver unit provided communication between the nodes and the network. Each of these units need power to work, this power is provided by the power unit [16]. In our work we are going to evaluate our motes in similar environment.

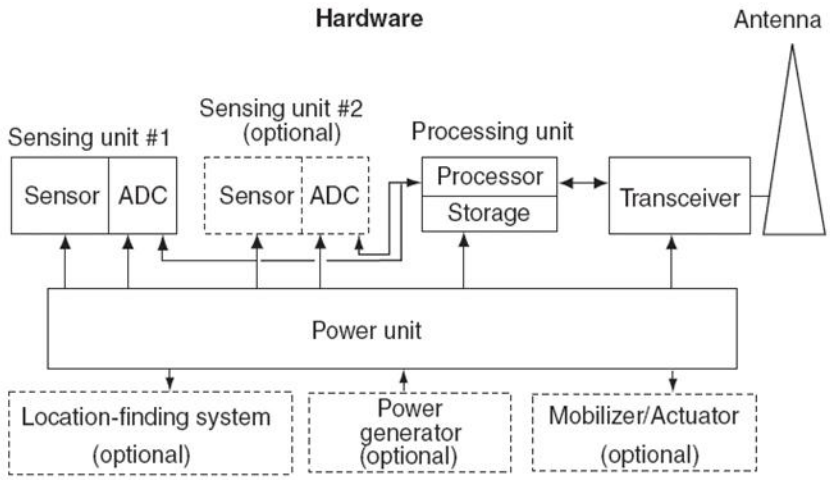


Figure 2 General architecture of a wireless sensing node [16].

Based on Berkeley motes, the authors in [8] conducted set of experiments in order to evaluate the performance of Mica2 and Mica2dot motes. In their study, they used maximum achievable throughput, and maximum transmission range for the comparison. They put into consideration some physical parameters, such as node distance from the ground, transmission data rate and environmental situation (weather conditions, humidity, temperature). In their study, they conducted many experiments using different scenarios. Each experiment was performed 10 times and then they took the average value over all replicas [8]. In our study, we will take the same considerations, using different generation of motes, in order to be sure that our experiments will be performed under the same conditions and we will use the average value as well.

Masashi Sugano et al. [20] perform an extensive measurement study to show the correlation between the RSSI and the distance between nodes. Their study aimed at evaluate the accuracy of position estimation system by using Ubiquitous Device, which is a sensor network system that performs communication based on the ZigBee standard.. The system in their study consists of three types of nodes which are targets, sensors, and a sink all run on the ubiquitous device. All communications during this study were performed by a single hop. In their study, the only information that used was RSSI in order to estimate the position of the target [20]. In our study we will show the relationship between the measured RSSI value and the distance between the base station and motes in deferent environments and situations.

The authors in [14] used the properties of received signal strength indication (RSSI) to implement indoor location system. A set of ZigBee wireless sensor nodes were used in order to implement their system. The network consists of five ZigBee nodes, four of them fixed and one mobile node. One of the four fixed nodes is connected to a laptop computer this node called ZigBee coordinator (ZC). The rest of the nodes called ZigBee routers (ZR). In their work, RF fingerprinting technique was used where that technique can be deployed in offline phase or the online phase. RSSI is used in the offline phase. They collect a set of measurement samples in a closed room. As they reported in their study, RSSI properties can be used in order to improve the localization applications. Our study will collect a set of measurement samples of RSSI in several situations and environments to compare the motes.

In [7] the authors conducted an experiment to investigate WSN nodes antenna radiation patterns determination using RSSI. According to their study, the antenna radiation pattern can considerably control distance determination between nodes. In our study we will use RSSI to show the impact of the surrounding environment on the transmitted signal.

Angela, D et al. [4] presented an environmental surveillance system using WSNs to monitor and locate inhabitant's moving behavior. Fig.2 show the network topology and hardware connections that used in their study. They used one mote as a base station connected to the PC and the other sensor nodes used to sense the environment in order to collect some data such as temperature, light etc. When the data collected, it sent immediately to the base station which forwards it to the PC. They use IRIS motes to implement that system where the motes were distributed in different places in the building. MoteView interface was used for monitoring and deployment. The results of that study were convincing to put WSNs technology into account when it's come to develop security systems and surveillance operations. In our study we will use IRIS as one of the two sensor types that will be evaluated using the same interface that used in this study which is MoteView.

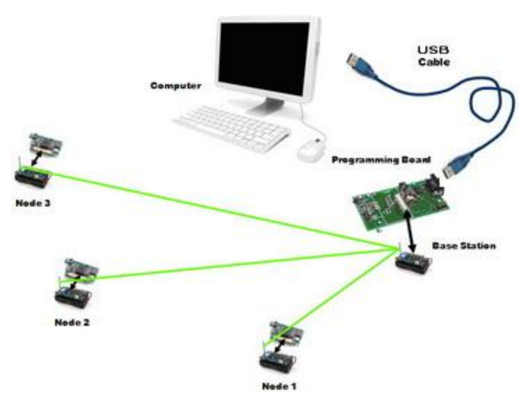


Figure 3 Hardware connections and network topology [4]

The utilization of RSSI in embedded nodes [26] and its reliability [3] were investigated deeply. These two studies gives clear idea how RSSI nature is random. This fact leads us to know that the RSSI value does not depend only on distance, but there are some other influences, such as power level, type of radio and antenna orientation. In our work we will see how much the surrounding environment could affect RSSI value.

The study closest to our work is one done by Harun, A et al. [11]. They perform a comparative measurement of three types of WSNs devices evaluated for application in a mixed-crop farm. IRIS, Xbee-PRO and Microchip motes are used in this study. In that study, researchers conducted experiments in a large open grass field in order to compare and evaluate the performances of the motes at different heights of the antenna. The base station was fixed in one place throughout the experiments whilst the other motes were placed at different distances from the base station in a straight line. The experiments were performed with antenna heights of 15 cm and 1 m. As they report in their work, there are two important factors that influence WSNs node performances which are antenna height and the type of antenna used. After analyzing the results that have been obtained through experiments, Xbee-PRO perform better than the other motes. In our work we will use IRIS and LOTUS motes to evaluate their performance using RSSI as one of the factors that will be used for measurements besides packet drops and Packet arrivals analysis.

Cirstea, C. et al. [6] carried out a study of the importance of packet loss consideration (PLC) in choosing the best communication path. They performed the experiments in an open area using 10 IRIS nodes placed on a straight line with 10 meters as a separation distance between the nodes. The duration of the test was three hours, where nodes were set to communicate every 10 seconds. The authors used packet loss in order to evaluate the quality of the link between network nodes instead of the received signal strength indicator (RSSI). As a result of their work, they show the influence of considering packet loss when choosing the best communication path on increasing network throughput. In our study we will use packet loss to compare the performance of evaluated motes.

In [28] the authors used packet loss and latency in order to measure motes' performance. In this study the authors performed the experiments in University of Texas at Austin using mica2 motes developed by UC Berkeley. They used Intramural Soccer Fields as the reference environment and to avoid the interference of humans, they conducted the reference experiment between 4:00 PM to 5:30 PM when there were few people in the area. They used this environment as reference environment with minimal interference as compared to other three environments. The three other environments were Almetris Duren Residence Hall, Earnest Cockrell Jr. Hall and BME Building all in University of Texas at Austin. In that study, they used one mote as base station installed on mib510 and connected to laptop through USB and one other mote acts as remote node. The experiment's procedure was to increase the distance between remote node and base station by an increment of 5 meters. As they report in their work the results shows that the motes performs in construction site not as good as open area. In our work we will evaluate the performance in open areas and in closed area what makes our study more comprehensive and accurate.

Lee, Ee Foong, Chen Wang and Li Xiao [18], explained how signal strength behaves in both indoor and outdoor environments. They placed the base station in a fixed position where the other node varied at the distances of 10ft, 20ft, 30ft, 40ft, 50ft, 60ft, 70ft, and 80ft from the base station. As a result of their work, they stated in their paper that it is always important where to place your sensor nodes. According to their study, the received signal strength will be stronger if you put your sensor nodes higher from the ground. In our work, we will put our motes on a small plastic tables at an equal distance from the ground for all motes and base station.

Another study, Kenyeres *et al*. [15] carried out a series of experiments to show the relationship between data rate and reliability of the whole WSNs. The experiment was realized with Crossbow WSNs class room Kit based on IRIS platform as we will use in our work. As they report there are three possibilities how to lower error rate and increase number of received packets for static WSNs: Reduce topology, Decrease the distance between nodes and Increase packet sending interval. In our study we will control the data rate using MoteView and LotusView interfaces.

The performance of the data MULE (Mobile Ubiquitous LAN Extensions) model and its ability to support sensor based applications in cities and populated areas were investigated in [9].The authors conducted experiments based on Berkeley motes (Mica2).The analyzed the results show the impact of distance and packet lose parameters on the performance of MULE. In our work we will use the same parameters that used in this study.

CHAPTER 3

EXPERIMENTS REQUIREMENTS

In this chapter we will introduce the hardware and the software requirements for this research for both IRIS and LOTUS wireless motes.

3.1 HARDWARE REQUIREMENTS

In this section we will list the equipment and tools that will be used in this study for both types IRIS and LOTUS wireless motes as follow:

3.1.1 IRIS

3.1.1.1 IRIS Mote

The IRIS is one of the latest generations of Motes from MEMSIC. The XM2110 (2400 MHz to 2483.5 MHz band) uses the Atmel RF230, IEEE 802.15.4 compliant, ZigBee ready radio frequency transceiver integrated with an Atmega1281 micro-controller (see figure 4)[22].

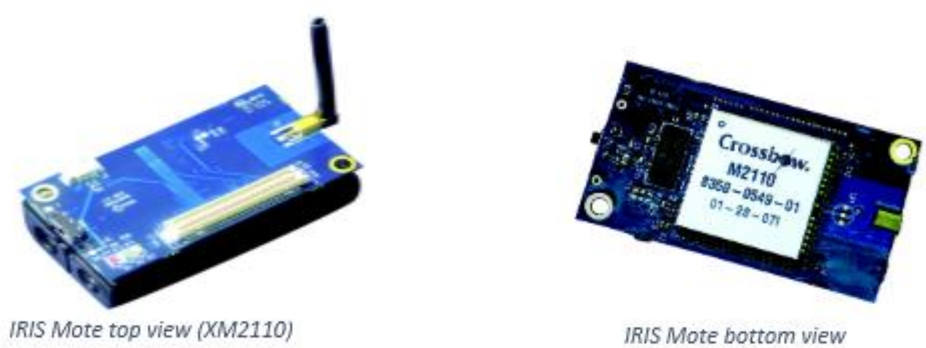


Figure 4 IRIS mote [22]

Table 1 IRIS Features[22]

Size	58 x 32 x 7 mm
Processor	XM2110 based on Atmel ATmega 128-1
RAM	8 Kb
Program Flash Memory	128K bytes
Frequency Range	2.4 – 2.48 GHz
Data Transmission Rate	250kbps
Transmission Range	Indoor more than 50m, outdoor up to 500m
Supply Power	2.7 – 3.3 V

3.1.1.2 Radio Boards

In this work we will use MIB520 USB Interface Board, The MIB520 provides USB connectivity to the IRIS Motes for communication and in-system programming. It supplies power to the devices through USB bus (see figure 5) [24].

Figure 5 MIB520 USB Interface Board [24]

3.1.1.3 Sensor Boards

In our research we are going to use MDA100 sensor board, where these boards have a precision thermistor, a light sensor/photocell, and general prototyping area [31]. (See figure 6).

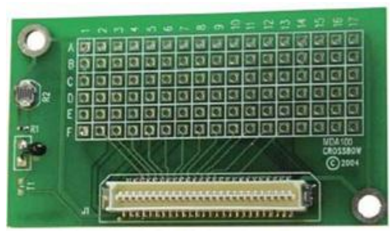


Figure 6 MDA100 sensor board [31]

In this study, MDA100 sensor board will be used with IRIS and LOTUS which means the packet format will be the same for both systems in this research where the packet structure or format is shown in Table 1.

Table 2 MDA100 Packet Structure

Bytes: 5	0/7	4	1	2	2	4	2
TinyOS Header	XMesh Header	XSensor Header	vref	Thermistor	photo	…	CRC
			MDA100 Payload				

The MDA100 payload has the following fields:

Table 3 Data Payload contents of MDA100 Packet

Type	Data Fields	Description
Uint16_t	**vref**	Battery reading (also known as vref or voltage)
uint16_t	**thermistor**	Temperature reading.
uint16_t	**photo**	Light sensor reading.
uint16_t	**adc2**	Analog to Digital Converter reading
uint16_t	**adc3**	Analog to Digital Converter reading
uint16_t	**adc4**	Analog to Digital Converter reading
uint16_t	**adc5**	Analog to Digital Converter reading
uint16_t	**adc6**	Analog to Digital Converter reading

3.1.2 LOTUS

3.1.2.1 LOTUS Mote

The LOTUS is an advanced wireless sensor node platform. It is built around the low-power Cortex M3 CPU and also integrates an 802.15.4 compliant radio. The LOTUS platform features several new capabilities that enhance the overall functionality of MEMSIC's wireless networking products and is compatible with MDA and MTS sensor boards (see figure 7). This mote can be used as a base station linked by cable to the laptop through the USB port [23].

LOTUS Mote top view (LPR2400)   LOTUS mote bottom view

Figure 7 LOTUS mote [23]

3.1.2.2 Sensor Boards

MDA100 sensor board will be used with LOTUS motes as we used it with IRIS which offers some basic environmental sensors (see figure 6).

3.1.3 Materiel in the field

There are some tools that will be used to help us conduct experiments properly and safely. We will present these tools briefly in this section as follow:

Table 4 LOTUS Features [23]

Size	76 x 34 x7 mm
Processor	low-power Cortex M3 CPU
RAM	64Kbytes
Program Flash Memory	512K bytes
Frequency Range	2.4 – 2.48 GHz
Data Transmission Rate	250kbps
Transmission Range	outdoor more than 500m
Supply Power	2.7 – 3.3 V

3.1.3.1. Plastic Boxes

In some experiments, we need to bury our motes under soil and sand, so we have to protect that motes by putting them inside these plastic boxes where these boxes would have no impact on the signal strength generated by the motes. (See figure 8).

Figure 8 Plastic Boxes

3.1.3.2. Plastic Table

We will use four small plastic tables in this study, one for the base station and three for the other three motes to keep all devices at same level from the ground where the impact of these plastic table on signal is neglectable. (See figure 9).

Figure 9 Small plastic tables

3.1.3.3. Metric Scale

We need this scale to measure distance between the motes and the base station during our experiments where we will work with different distances (5, 10, 15 meters) (see figure 10).

Figure 10 Metric Scale

3.2 SOFTWARE REQUIREMENTS

This section reviews the software requirements that needed to install software which will be used during this study as follow:

3.3 MoteView and LotusView

MoteView and LotusView are designed as interface between the user and sensors. These two applications provide the tools to simplify deployment and monitoring. They also make it easy to connect to a database, to analyze, and to graph sensor readings.

Before we can use MoteView for IRIS or LotusView for LOUS we have to install these two programs on a PC. That PC should have one of the following operating systems

- Windows XP Home/Professional
- Windows 2000 with SP4
- Windows 7 / 8

In this study we will work with Windows 8 operating system.

3.3.1 XSniffer

In this study we will use multi-hop communication in order to analyze and monitor the packet arrivals, XSniffer allows users to monitor multi-hop communication over XMesh. This program runs on a PC and uses an IRIS or LOTUS Mote to monitor the RF packet traffic.

3.3.2 Other Softwares

In this study we used other programs such as Matlab and Excel to represent and analyze the results in a better way. We also used Eye in Sky Android application which is a weather app for Android phones, we used that application to monitor the wind speed during the experiments where we stop or cancel the work if the wind speed more than 20 Km/h because the winds caused some technical problems which definitely affect the performance.

CHAPTER 4

EXPERIMENTS METHODOLOGY AND PREPARTION

There are two sections in this chapter, in the first section we will describe the research methodology that we will follow while doing these experiments. The second section will explain the final preparation and configuration to use wireless motes properly.

4.1 Research Methodology

As we mentioned before, the main objective of this research is to evaluate the performance for two generations of WSN motes in terms of communication in different situations and environments. The study will include evaluation of the installation process of each type and performance in different environments. The research is restricted to evaluate the performance of each network formed by three motes and one base station, which are sufficient to produce results that will give us a clear idea about the efficiency of these wireless motes in such environments.

High power level will be used in this study when we program our motes, where motes can be programmed using high power HP mode or low power LP mode.

We will set the data message interval (DMI) to 3-second, which means each mote will send one packet every 3 seconds.

In this study, we will use three criteria, the first one is received signal strength indicator (RSSI), where RSSI will show the sensitivity of the signal to the surrounding environment. The second measure that we are going to use in this research is Packet drops rate, where the high packet drop rate can cause noticeable effects on any system efficiency leading to system failure. The third criteria that will be used in analyzing and evaluating the used wireless motes during this research is Packet arrivals analysis.

In this research, the methodology is as simple, accurate, and clear as possible, we will run, monitor and evaluate these two type of wireless sensor networks accordance to the following scenarios:

4.1.1 First Scenario:

In this scenario, the base station will be placed in the middle surrounded by three nodes where the distance between the base station and other nodes is 5 meters in the first experiment then 10 meters in the second experiment and finally 15 meters in the third experiment for each direction as we can (see figure 11). This scenario will be implemented in eight different environments (open area, closed area, under soil, under sand, palm field, maize field, parking and valley) for each type of the two wireless motes, which means 3*8*2 (3 distances, 8 environments, 2 types of motes), so the total will be 48 experiments for this scenario. This scenario will give us data related to RSSI and Packet Drop criteria.

4.1.2 Second Scenario:

The first scenario will be good to evaluate the RSSI and Packet drops, but for the Packets arrival analysis we used multi-hop routing scenario (see figure 12). Multi-hop routing involves sending signals through multiple stops instead of one long pathway which means the packet need long time to reach its destination. In this scenario, we aimed to measure that time to monitor and analyze the packets arrival (see figure 12). In this scenario we have 2* 8 (2 motes and 8 environments), so the total will be 16 experiments.

The total experiments according to these two scenarios will be 48+16= 64 experiments.

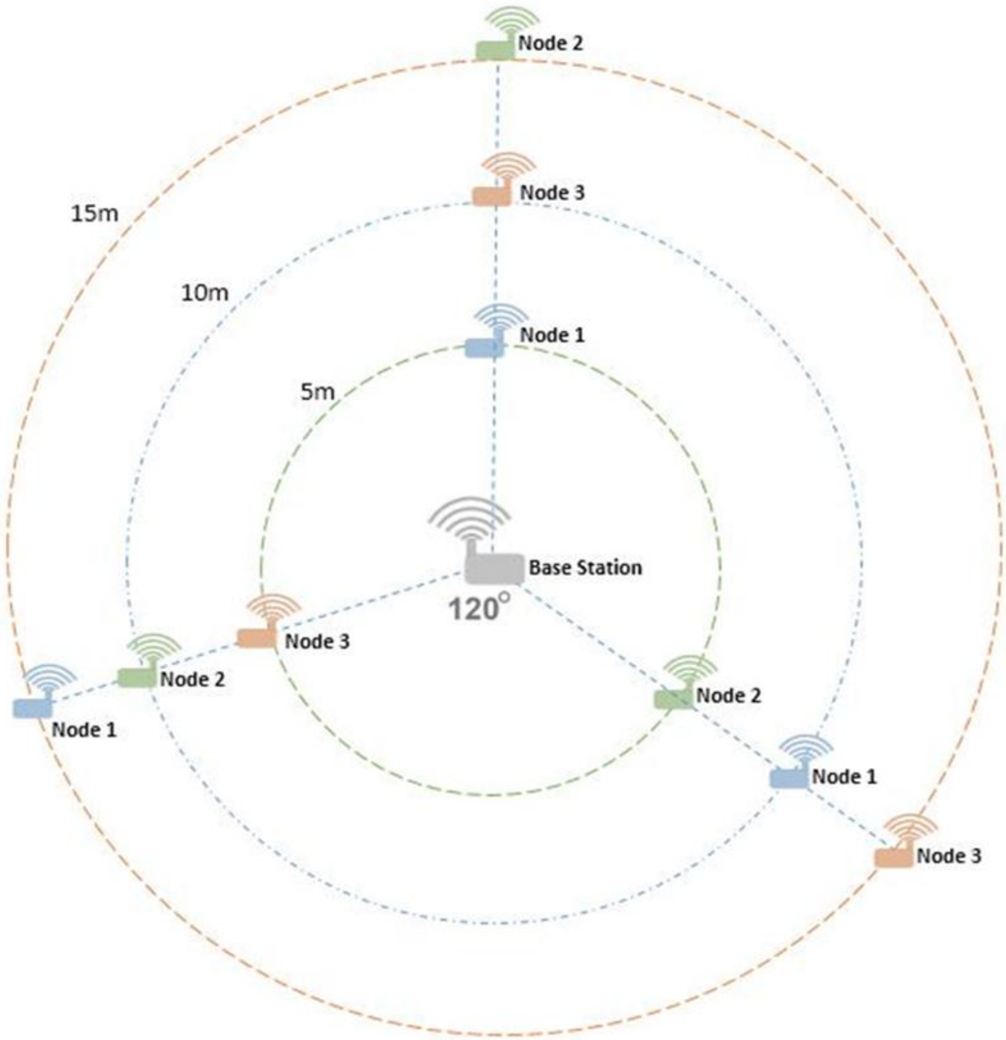


Figure 11 first scenario

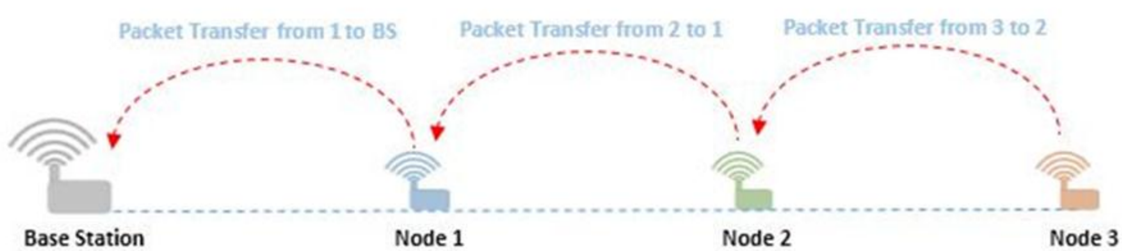


Figure 12 second scenario

4.2 Experiments Preparation

In Appendix 1, we provide the initial setup for IRIS and LOTUS motes, how the sensor nodes are programmed, and all what we need to start our experiments.

4.2.1 Installation time

The time spent on the installation process mainly depends on the device strength to which you have installed the application on. In this study we used Dell Inspiron 15 7000 series, Core i7-4500U Processor and 8 GB DDR3L-1600 RAM which is a powerful laptop come with windows 8 operating system (see figure 13).

Figure 13 Dell Inspiron used laptop

The table below show the installation timing for IRIS application “MoteView” and LOTUS application “LotusView” on our PC and running the system.

Table 5 installation timing for IRIS/ LOTUS application

Task	IRIS	LOTUS
Install MoteView/LotusView	5 min.	5 min.
Connect the mote and install driver	1 min.	3 min.
Connect the mote and program it	3min. (1 min. for each)	3min. (1 min. for each)
Connect the mote and program it as a base station	1 min.	1 min.
Connecting the Base mote and the sensor mote and receive the first packet	2 min	2 min
Over all time	12 min.	14 min.

CHAPTER 5

FIELD EXPERIMENTS

In this chapter, we will explain the conducted experiments in details and we will show how the two types of motes perform in the real environments. We will describe each experiment individually and at the end of this chapter we will show all results together to get a clear idea of the WSN motes performance.

At the beginning of this experiment, we put the base station in the middle and distributed the three motes all around it in different directions at 5 meters distance between the base station and each mote where we used the first scenarios described earlier in section 4.1. One hour later, the data collected and then we changed the motes positions and increased the distance between the base station and motes to 10 meters. One hour later, the data collected and again we changed the motes positions and increased the distance between the base station and motes to 15 meters where we collected data for one hour. When we finished collecting data using the first scenario, we start the second scenario described earlier in section 4.1. at this scenario we collected data for one hour using the multi- hop routing where the mote3 connected to mote 2 and mote 2 connected to mote 1 and finally mote 1 connected to the base station.

The measurements took about 4 hours for each system, IRIS and LOTUS where packet transmission rate is (3 seconds), then we took the average of RSSI and Packet dropping from the data collected by using the first scenario and analyze the Packet arrivals using the data collected from the second scenario. We used MoteView application as a monitor for the IRIS and for the LOTUS we used LotusView and Xsniffer application used for the second scenario. We converted RSSI raw values using the information provided in [32] and [33].

5.1 Closed Area Experiments

The main objective of this experiment is to show the performance of the two generations of WSN motes in the closed area where there is no wind or dust or any kind of obstacles between the motes and the base station. We have conducted this experiment at KFUPM gym hall (Building 11) during the spring vacation where there was no one at the gym (See figure 14).

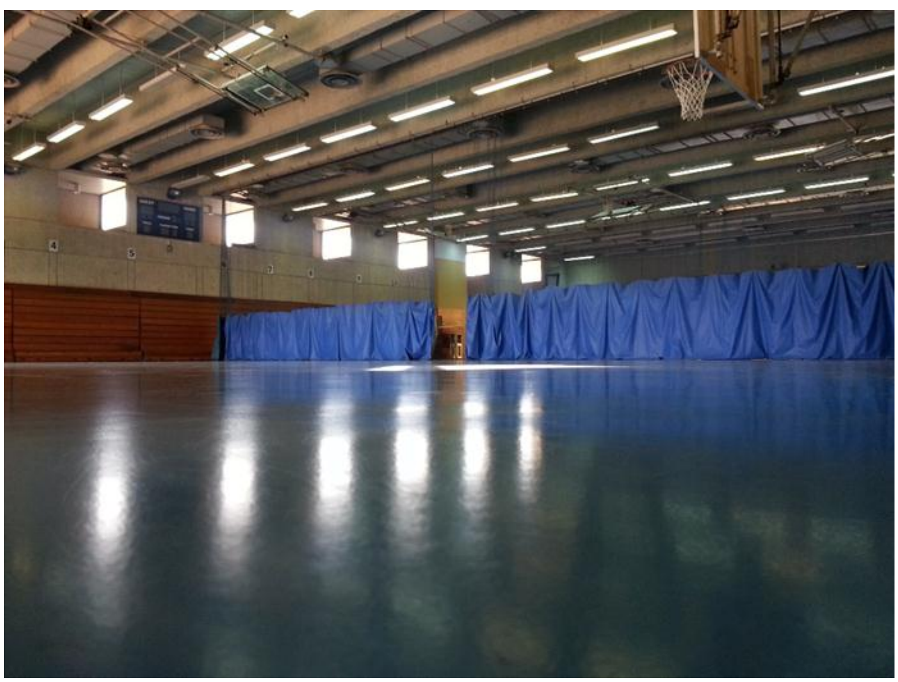


Figure 14 KFUPM gym hall

IRIS LOTUS

Figure 15 IRIS and LOTUS Equipment for close area Exp.

5.1.1 Closed Area Experiments results

When we finish the experiment, we collected, filtered and analyzed data. Table 6 show the values that we got by doing this experiment.

From Figure 16, we can observe that LOTUS motes perform better than IRIS motes according to the RSSI reading, but in general they both worked very well in such environment. Table 6 shows the confidence interval of RSSI for both systems which giving us a clear idea how good was the RSSI average. Figure 17 show the stability of RSSI for both IRIS and LOTUS for one mote at 15m distance. We can see that RSSI of IRIS is more stable than LOTUS.

Table 6 all results for closed area Exp.

IRIS 5m Closed overall average		
Node	RSSI dBm	Drop
1	-45	1.73%
2	-47	1.82%
3	-48	2%
Average	-47	1.85%

LOTUS 5m Closed overall average		
Node	RSSI dBm	Drop
1	-38	1.60%
2	-38	1.38%
3	-38	1.85%
Average	-38	1.61%

IRIS 10m Closed overall average		
Node	RSSI dBm	Drop
1	-57	2.12%
2	-58	2.50%
3	-58	2.25%
Average	-58	2.29%

LOTUS 10m Closed overall average		
Node	RSSI dBm	Drop
1	-49	2.09%
2	-49	1.87%
3	-50	1.86%
Average	-49	1.94%

IRIS 15m Closed overall average		
Node	RSSI dBm	Drop
1	-67	2.69%
2	-67	2.88%
3	-67	2.93%
Average	-67	2.83%

LOTUS 15m Closed overall average		
Node	RSSI dBm	Drop
1	-58	2.25%
2	-59	2.23%
3	-59	2.24%
Average	-59	2.24%

IRIS Packet Inter-Arrival"Sec."		
Average	2.98	
Confidence Interval for RSSI		
5m	10m	15m
± 0.16	± 0.1	± 0.09

LOTUS Packet Inter-Arrival"Sec."		
Average	2.97	
Confidence Interval for RSSI		
5m	10m	15m
± 0.25	± 0.17	± 0.17

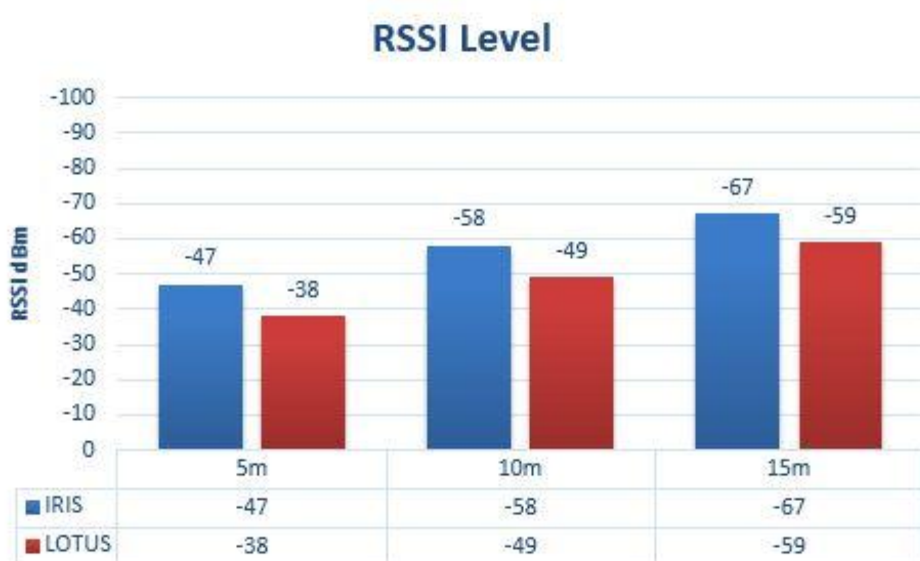


Figure 16 RSSI level for closed area Exp.

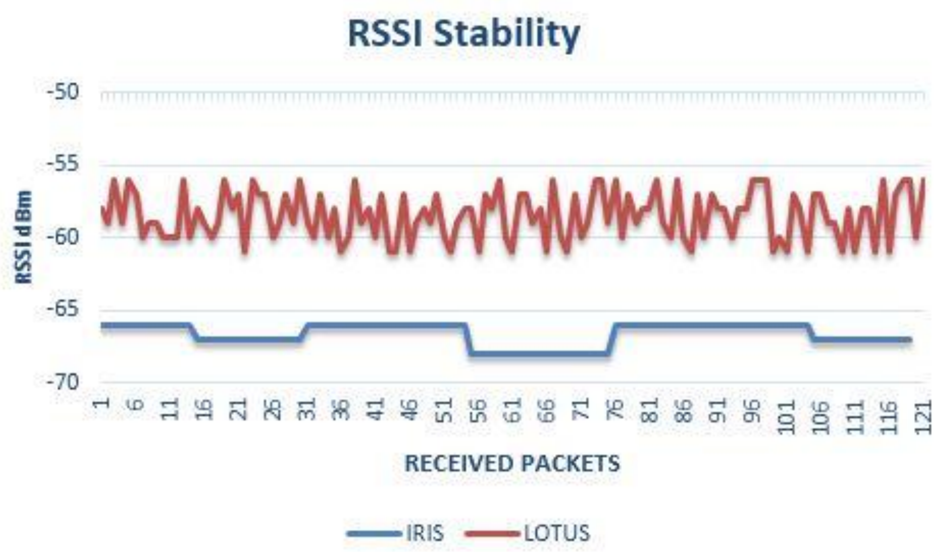


Figure 17 RSSI stability for closed area Exp.

The second criteria that we measured is packet drop. Figure 18 show the percentage of packet dropping during the time of the experiment. The results show no significant difference between the two generations of WSN regarding to the packet dropping in this situation, there is little advantage to the LOTUS motes as shown in figure 18.

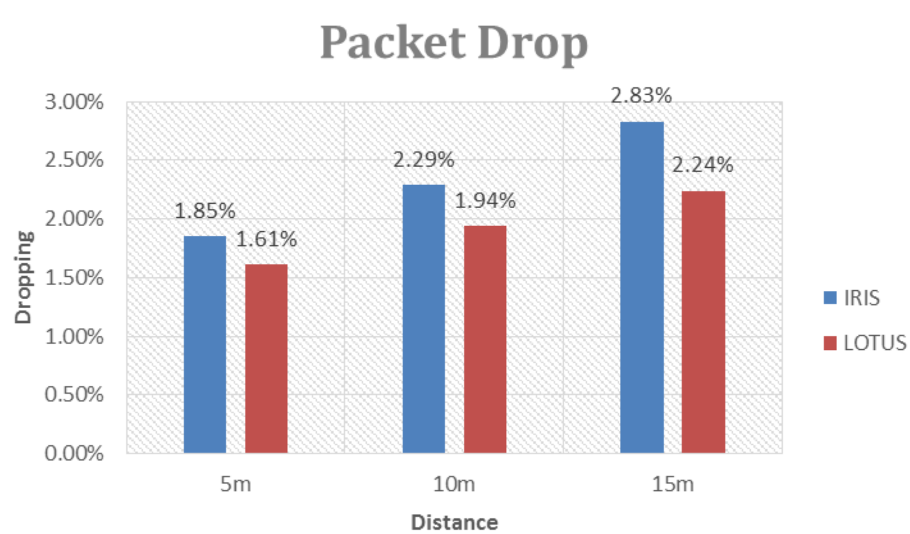


Figure 18 Packet drop for closed area Exp.

The third criteria that we used to evaluate the performance is Packet arrivals analysis. We analyzed the collected data statistically where we calculate the cumulative distribution and the probability density for the packet inter arrival as shown in figures 20, 21 respectively.

Figure 19 show the packet inter arrivals in seconds where we used Xsniffer to sniff the packet arrivals to the base station. We follow the second scenario for this measurement, where mote 3 send the packet to node 2 and node 2 forward it to node 1 and finally to the base station, at that time Xsniffer sniff the received packet and accurately record time.

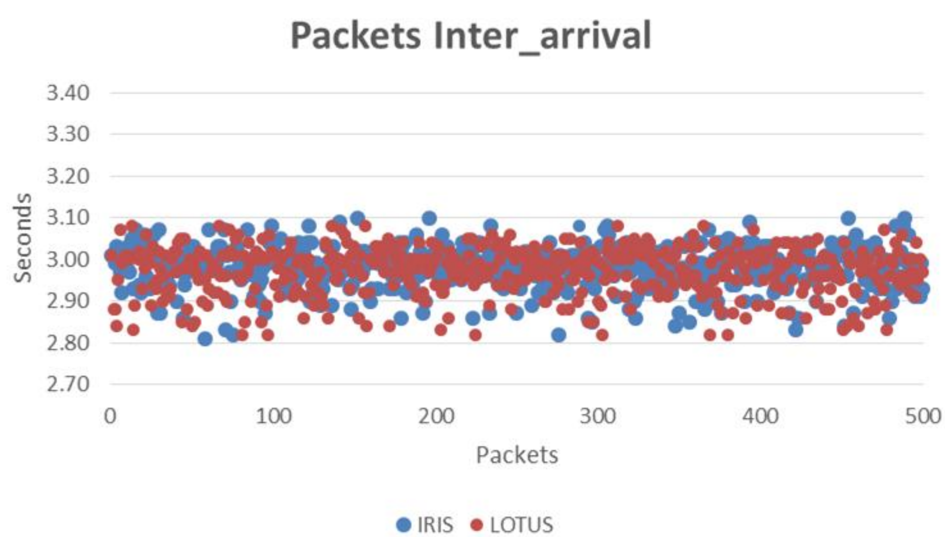


Figure 19 packet inter arrivals for IRIS and LOTUS

As shown in figure 19, the arrival of packets sending from mote 3 to the base station was between 2.8 and 3.1 seconds but the majority of inter-arrival packets was around 3.01 seconds.

Figures 20 and 21 shows the cumulative distribution and the probability density for the packet inter arrival respectively.

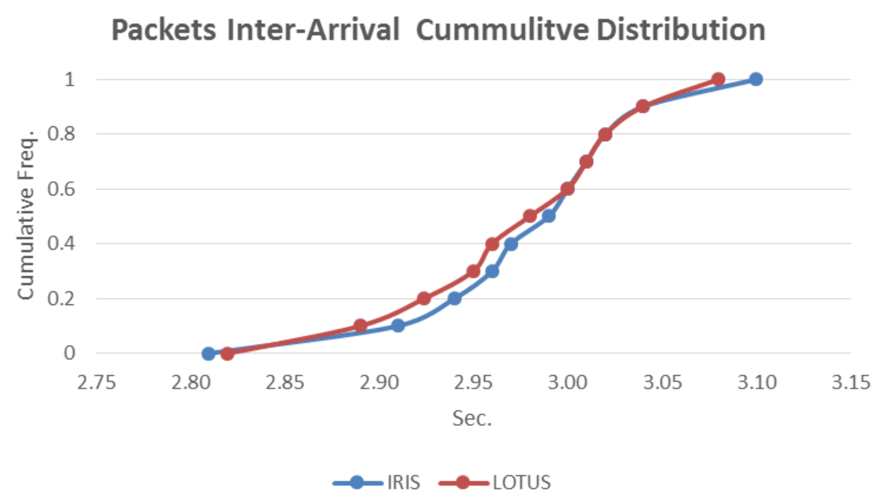


Figure 20 Packet Inter- Arrival Cumulative Distribution for close area Exp.

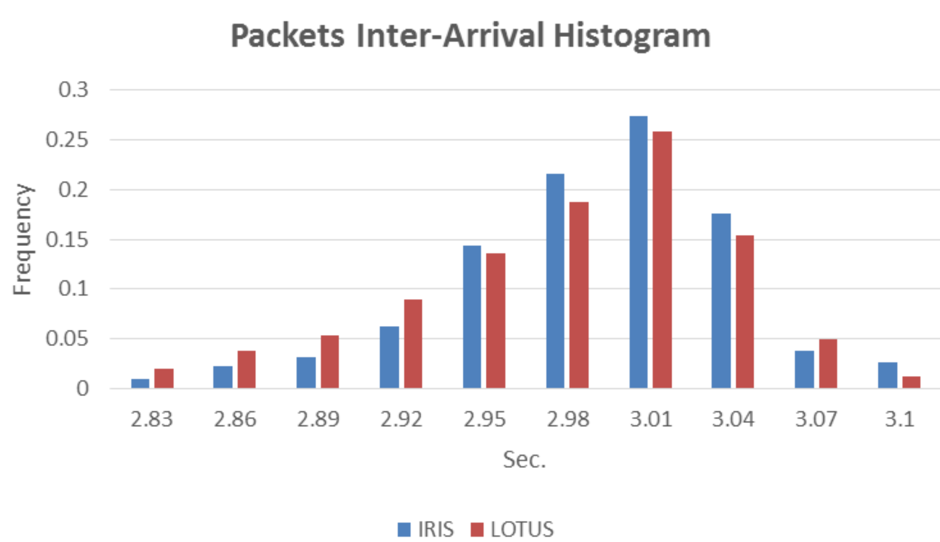


Figure 21 packets Inter-Arrivals Histogram for closed area Exp.

At the end of this experiments, we can say that LOTUS motes was slightly better than IRIS motes, but in general both motes performed nicely in such environment.

5.2 Open Area Experiments

This experiment was conducted in the province of Shabowah, Yemen in a flat open area where there are no buildings at all, (see figure 22). In this experiment, we will see how motes will perform under normal weather conditions where it is not too windy neither dusty nor rainy.

Figure 22 Open area

IRIS *LOTUS*

Figure 23 IRIS and LOTUS Equipment for open area Exp.

5.2.1 Open Area Experiments results

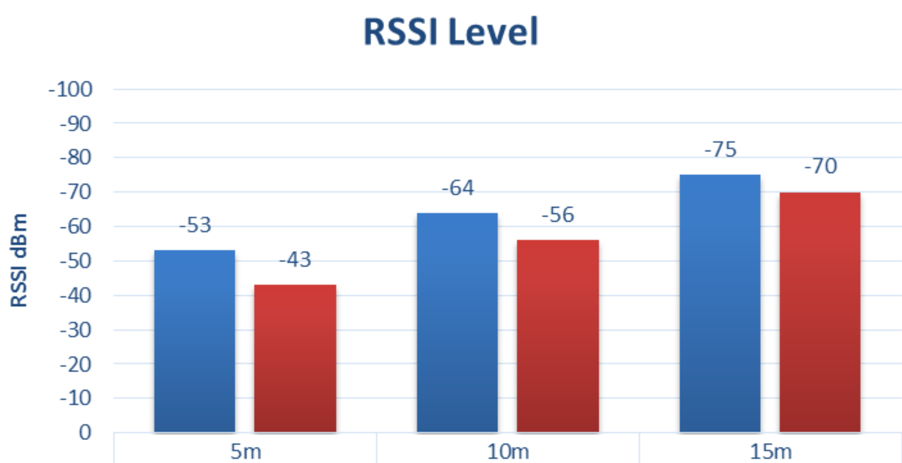
We have compiled the data after the completion of the experiments and analyzed it. Table 7 summarizes all the results obtained during these experimentations.

Table 7 All results for open area Exp.

IRIS 5m Open overall average		
Node	RSSI dBm	Drop
1	-54	2.83
2	-53	3.1
3	-53	3.2
Average	-53	3.1
IRIS 10m Open overall average		
Node	RSSI dBm	Drop
1	-64	3.5
2	-64	3.9
3	-63	3.91
Average	-64	3.77
IRIS 15m Open overall average		
Node	RSSI dBm	Drop
1	-75	4.32
2	-75	4.68
3	-74	4.62
Average	-75	4.54
IRIS Packet Inter-Arrival"Sec."		
Average	3.08	
Confidence Interval for RSSI		
5m	10m	15m
± 0.12	± 0.14	± 0.13

LOTUS 5m Open overall average		
Node	RSSI dBm	Drop
1	-43	2.62
2	-43	2.76
3	-43	2.63
Average	-43	2.67
LOTUS 10m Open overall average		
Node	RSSI dBm	Drop
1	-56	3.5
2	-57	3.38
3	-56	3.49
Average	-56	3.46
LOTUS 15m Open overall average		
Node	RSSI dBm	Drop
1	-69	4.33
2	-70	4.2
3	-70	4.32
Average	-70	4.28
LOTUS Packet Inter-Arrival"Sec."		
Average	3.06	
Confidence Interval for RSSI		
5m	10m	15m
± 0.2	± 0.33	± 0.45

Figure 24 shows the results of RSSI values in open area for both IRIS and LOTUS motes. It shows a significant difference between the two results mainly at 5m distance for the benefit of LOTUS motes, but this difference is gradually decreases with distance as shows in figure 24. Table 7 shows the confidence interval of RSSI for both systems which giving us a clear idea how good was the RSSI average.



	5m	10m	15m
IRIS	-53	-64	-75
LOTUS	-43	-56	-70

Figure 24 RSSI level for open area Exp.

The RSSI level is better for the LOTUS motes as an average, but when we look for the stability of RSSI, we will notice that the stability is much better for the IRIS as we can see in figure 25.

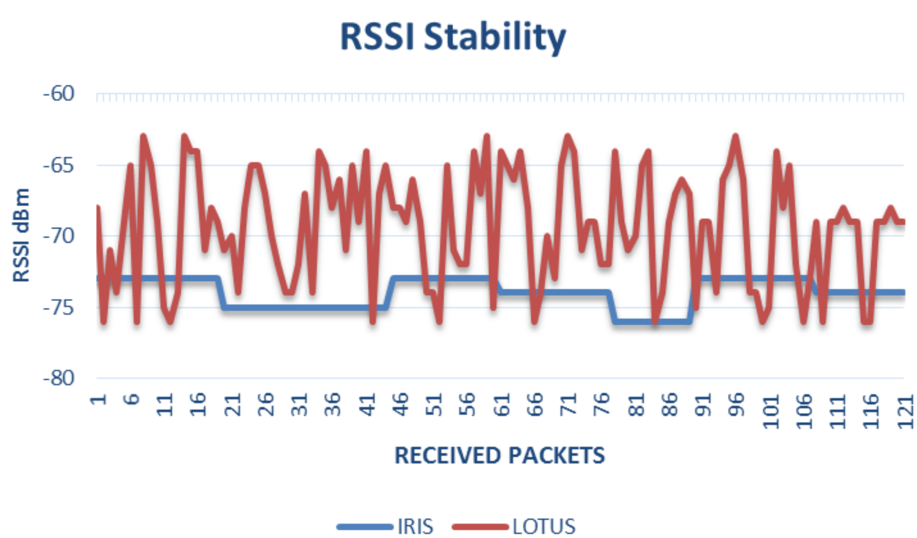


Figure 25 RSSI stability for open area Exp.

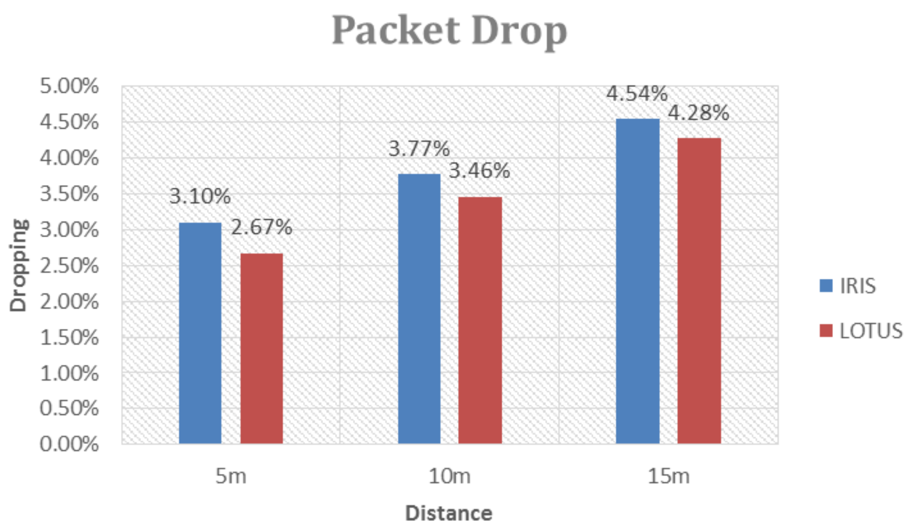


Figure 26 Packet drop for open area Exp.

Figure 26 shows the dropping in percentage for both WSN types. It is clear from the figure that IRIS motes lose more packets than LOTUS. We can note that there is a relationship between distance and packet drop, the more the distance, the more dropping we got.

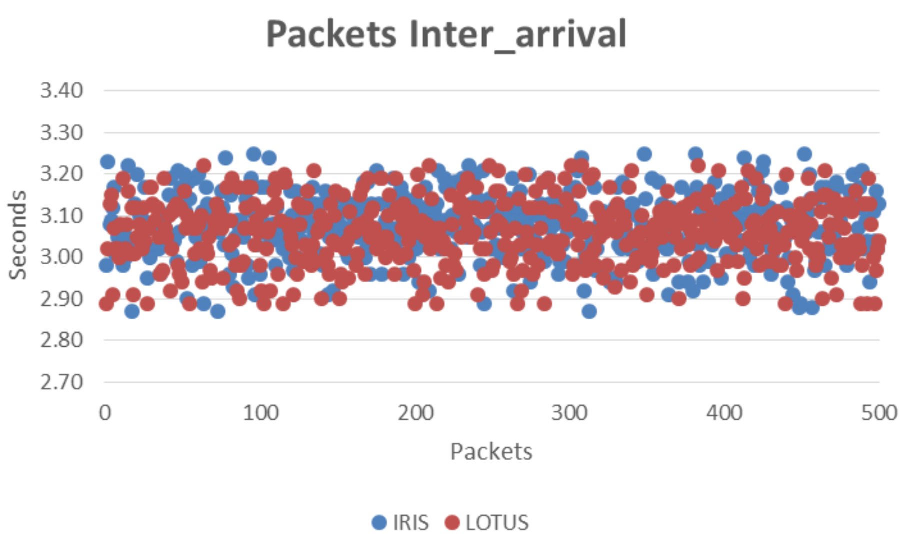


Figure 27 packet inter arrivals for IRIS and LOTUS

The packet inter-arrival is as shown in figure 27. We can see clearly that the packets arrivals is between 2.85 and 3.25 seconds and the majority of packets inter- arrival is around 3.09 seconds which is greater than the result of closed experiments which was 3.01 seconds. We can explain that by the surrounded conditions such as winds and dust so the packet need more time to reach the base station.

Figures 28 and 29 shows the cumulative distribution and the probability density for the packet inter arrival respectively.

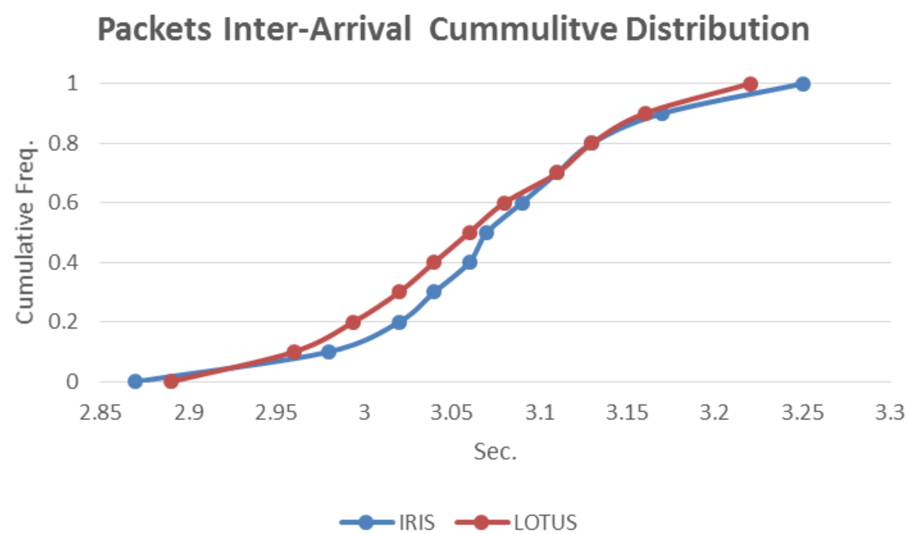


Figure 28 Packet Inter- Arrival Cumulative Distribution for open area Exp.

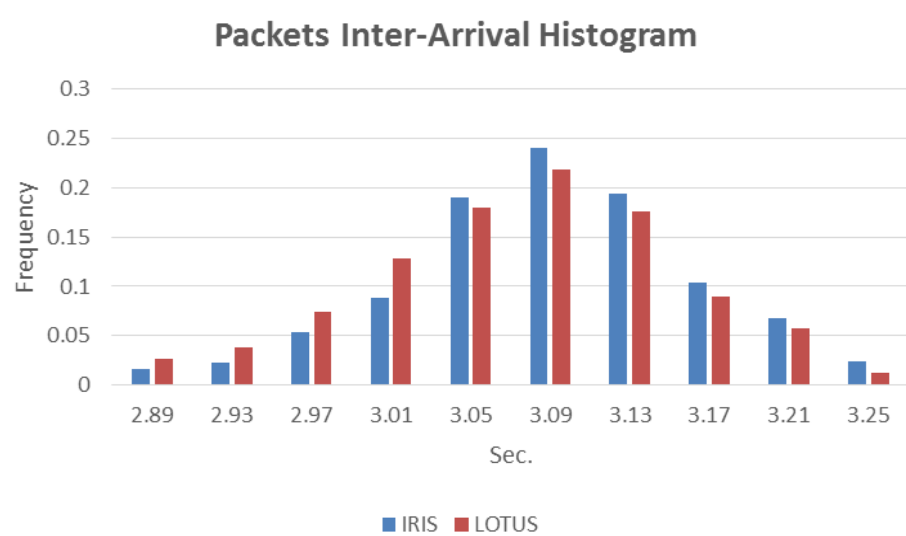


Figure 29 packets Inter-Arrivals Histogram for open area Exp.

At the end, the differences were not significant between the IRIS and LOTUS motes in this environment. They perform excellently with slightly preponderance for LOTUS motes as we have noted above.

5.3 Maize Field Experiments

We have selected a large maize (corn) field where the planting density is high as we can see in figure 30. The main objective of this experiment is to show how the planting density effect the signal transfer.

Figure 30 Maize Field

IRIS LOTUS

Figure 31 IRIS and LOTUS Equipment for maize field Exp.

We put the base station in the middle of the field then we distributed the other three motes around it to be surrounding from all sides where we increase the distances and change the mote`s location every time.

5.3.1 Maize Field Experiments results

We spent two days doing the experiments at maize field. Table 8 summarizes the results obtained during those two days.

RSSI level for maize field is shown in figure 32, these values indicate how strong is the impact of the planting on the signal transfer. The RSSI value decreases strongly from around -65 to -85 dBm for the IRIS motes and it is also decreases for the LOTUS from -64 to -79 dBm. Accordingly, we can say that signal is more sensitive if there is plants density in the way to the destination. Table 8 shows the confidence interval of RSSI for both systems.

Table 8 all results for maize field Exp.

IRIS 5m Maize overall average		
Node	RSSI dBm	Drop
1	-65	4.45
2	-65	5.25
3	-65	5.68
Average	-65	5.13

IRIS 10m Maize overall average		
Node	RSSI dBm	Drop
1	-77	6.76
2	-76	7.45
3	-77	7.8
Average	-77	7.34

IRIS 15m Maize overall average		
Node	RSSI dBm	Drop
1	-85	9.62
2	-85	9.58
3	-85	9.74
Average	-85	9.65

IRIS Packet Inter-Arrival"Sec."		
Average	3.1	
Confidence Interval for RSSI		
5m	10m	15m
±0.14	±0.13	±0.19

LOTUS 5m Maize overall average		
Node	RSSI dBm	Drop
1	-63	3.24
2	-64	3.13
3	-64	3.26
Average	-64	3.21

LOTUS 10m Maize overall average		
Node	RSSI dBm	Drop
1	-72	4.75
2	-72	4.64
3	-72	4.75
Average	-72	4.71

LOTUS 15m Maize overall average		
Node	RSSI dBm	Drop
1	-79	5.62
2	-79	5.85
3	-79	5.51
Average	-79	5.66

LOTUS Packet Inter-Arrival"Sec."		
Average	3.07	
Confidence Interval for RSSI		
5m	10m	15m
±0.25	±0.15	±0.14

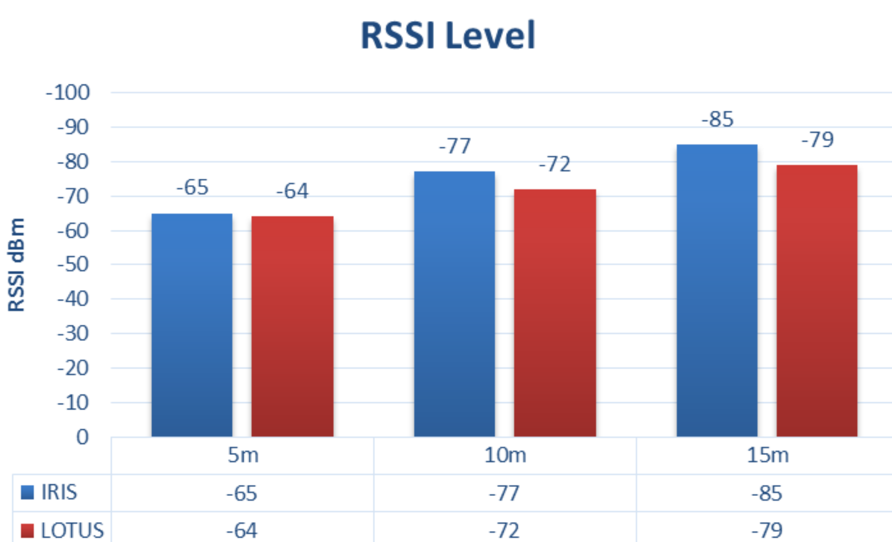


Figure 32 RSSI level for maize field Exp.

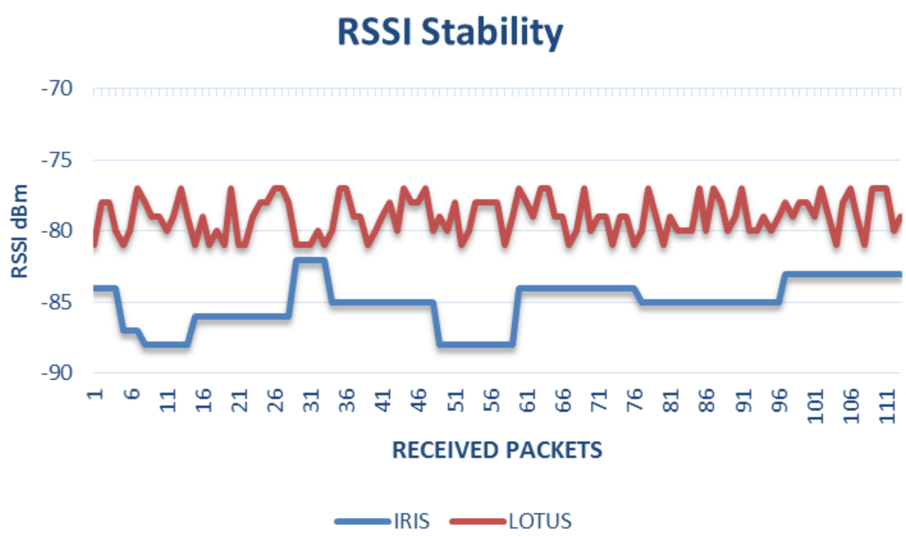


Figure 33 RSSI stability for maize field Exp.

As we mentioned before, the signal is very sensitive while it is traveling to its destination, figure 33 show the stability of RSSI for node 1 at distance 15m for both IRIS and LOTUS motes. We can see that signal is not stable it go up sometimes and down at other times.

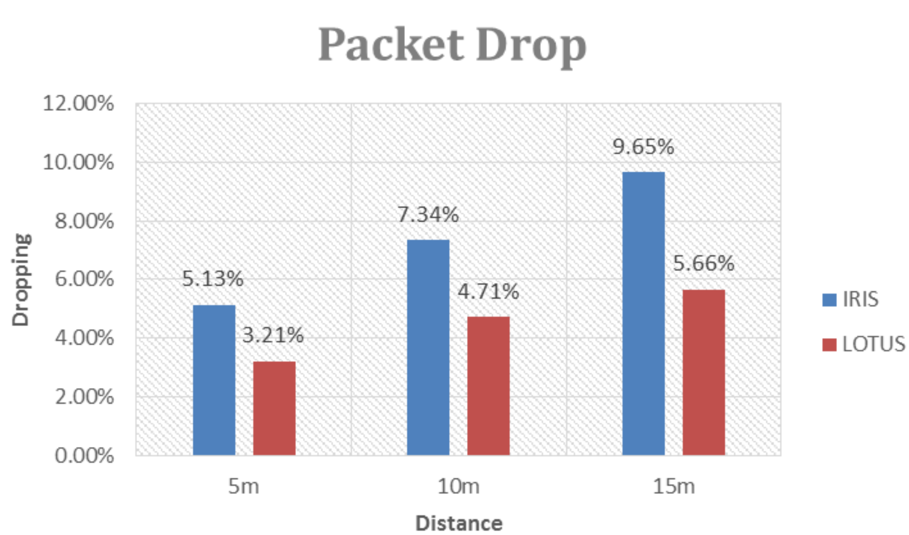


Figure 34 Packet drop for maize field Exp.

Figure 34 shows the packet drop during the experiments, it is obvious that both type of WSN affected by the surrounding environment. IRIS lose about 10 percent of the sent packet at 15 meters which is a high rate may affect the efficiency of any system.

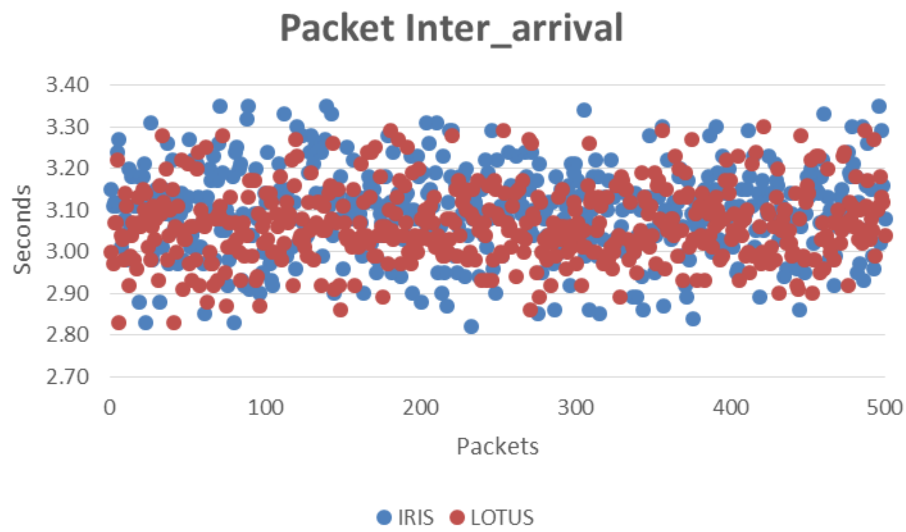


Figure 35 packet inter arrivals for IRIS and LOTUS

We saw the impact of plant density on RSSI and packet drop rate, figure 35 shows that impact on packet inter-arrivals. The packet inter-arrivals is between 2.82 and 3.35 seconds and the majority of packet arrivals is around 3.13sec. for IRIS and 3.08sec. for LOTUS. The only explanation for that is the plant density in the maize field.

Figures 36 and 37 shows the cumulative distribution and the probability density for the packet inter arrival in this environment respectively.

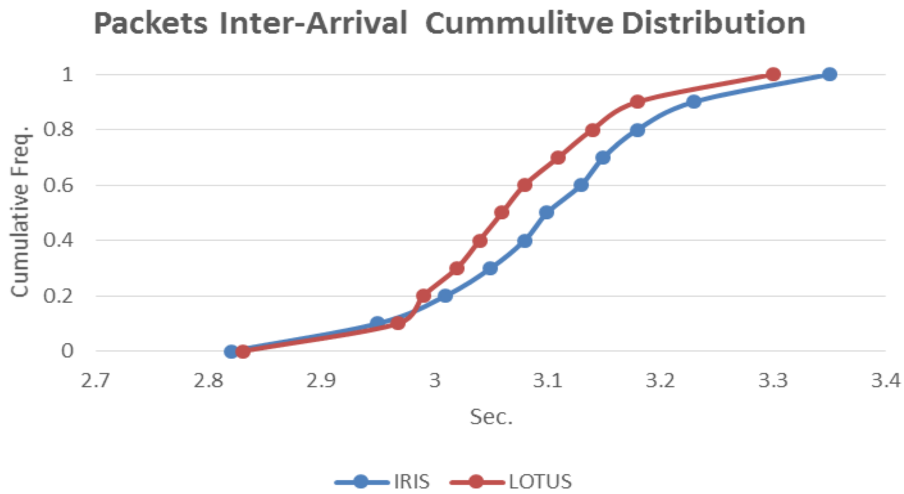


Figure 36 Packet Inter- Arrival Cumulative Distribution for Maize field Exp.

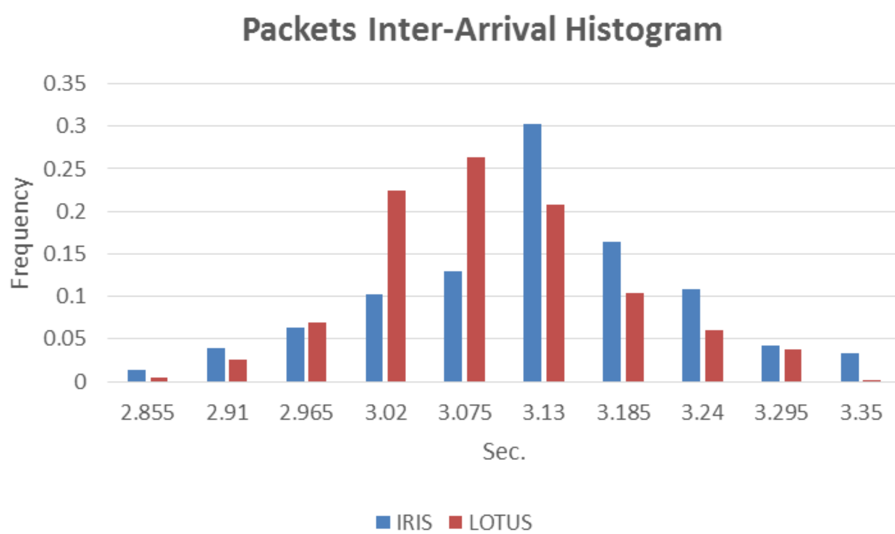


Figure 37 packets Inter-Arrivals Histogram for Maize field Exp.

At the end, we can see that IRIS and LOTUS motes performed well at short distances but IRIS motes performed badly as we increased the distance.

5.4 Palm Field Experiments

These experiments were conducted in a large palm field where at least there are 3 meters distance between each tree and other (see figure 38). The distance between the palm trees may allow the signal to transfer smoothly between motes and base station.

Figure 38 Palm Field

Figure 39 IRIS and LOTUS Equipment for palm field Exp.

5.4.1 Palm Field Experiments results

In this section we will represent the collected results to show how motes performed in this environment. Results summary is shown in table 9.

Table 9 All results for palm field Exp.

IRIS 5m Palm overall average		
Node	RSSI dBm	Drop
1	-60	4.66
2	-59	4.82
3	-60	4.96
Average	-60	4.81
IRIS 10m Palm overall average		
Node	RSSI dBm	Drop
1	-74	5.42
2	-74	5.52
3	-73	5.18
Average	-74	5.37
IRIS 15m Palm overall average		
Node	RSSI dBm	Drop
1	-81	7.6
2	-80	7.1
3	-80	7.13
Average	-80	7.28
IRIS Packet Inter-Arrival"Sec."		
Average	3.10	
Confidence Interval for RSSI		
5m	10m	15m
± 0.12	± 0.06	± 0.17

LOTUS 5m Palm overall average		
Node	RSSI dBm	Drop
1	-57	2.75
2	-57	2.97
3	-57	2.98
Average	-57	2.9
LOTUS 10m Palm overall average		
Node	RSSI dBm	Drop
1	-64	4.98
2	-65	4.94
3	-65	5.1
Average	-65	5
LOTUS 15m Palm overall average		
Node	RSSI dBm	Drop
1	-72	5.62
2	-71	5.5
3	-71	5.18
Average	-71	5.43
LOTUS Packet Inter-Arrival"Sec."		
Average	3.09	
Confidence Interval for RSSI		
5m	10m	15m
± 0.21	± 0.33	± 0.32

Figure 40 shows the level of RSSI that we got after conducting experiments, it shows the good performance of motes at different distances with a preference for LOTUS motes as usual. From the figure we can say that motes worked very well in terms of RSSI, it might be due to the distance between the palm trees which allow the transferring of signals to go through it. Table 9 shows the confidence interval of RSSI for both systems which giving us a clear idea how good was the RSSI average.

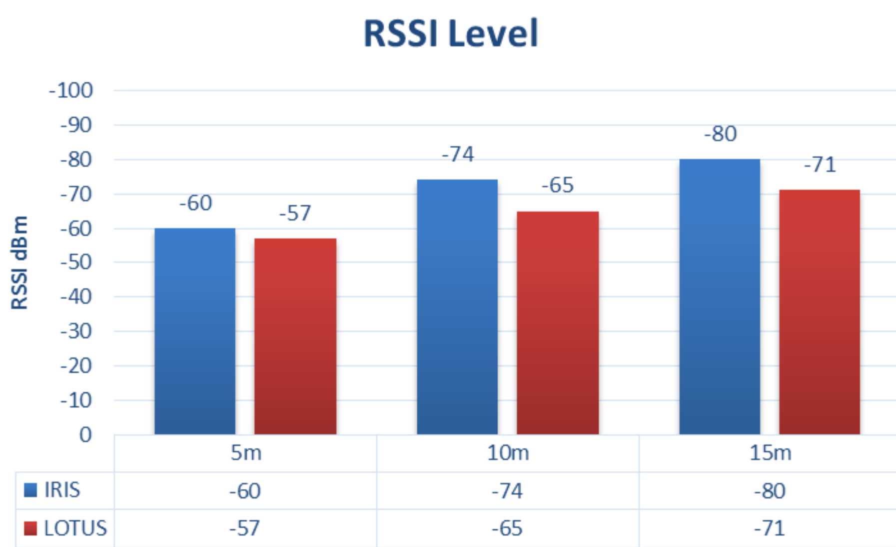


Figure 40 RSSI level for palm field Exp.

Figure 41 shows how stable is the RSSI level for both types, we can see that IRIS mote is more stable as usual. LOTUS RSSI is constantly volatile which might is not good for some applications such as security applications that use RSSI.

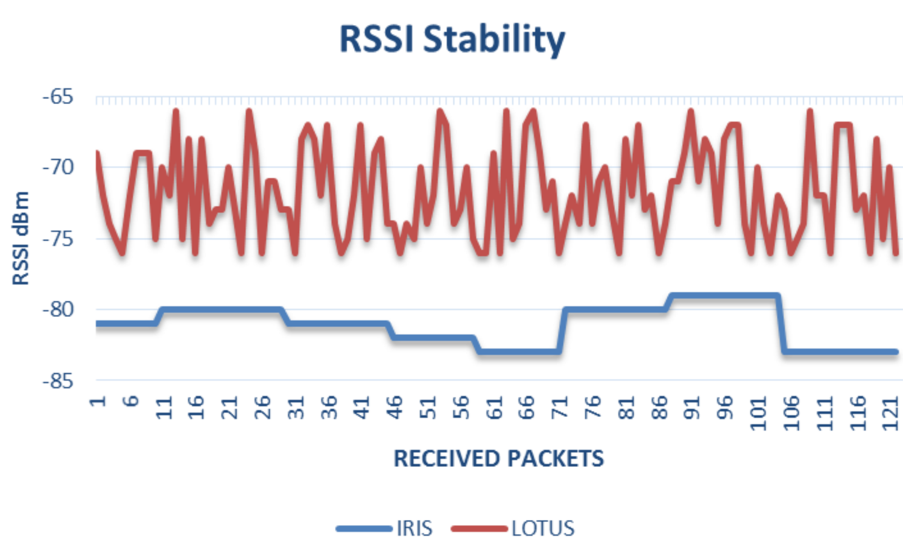


Figure 41 RSSI stability for palm field Exp.

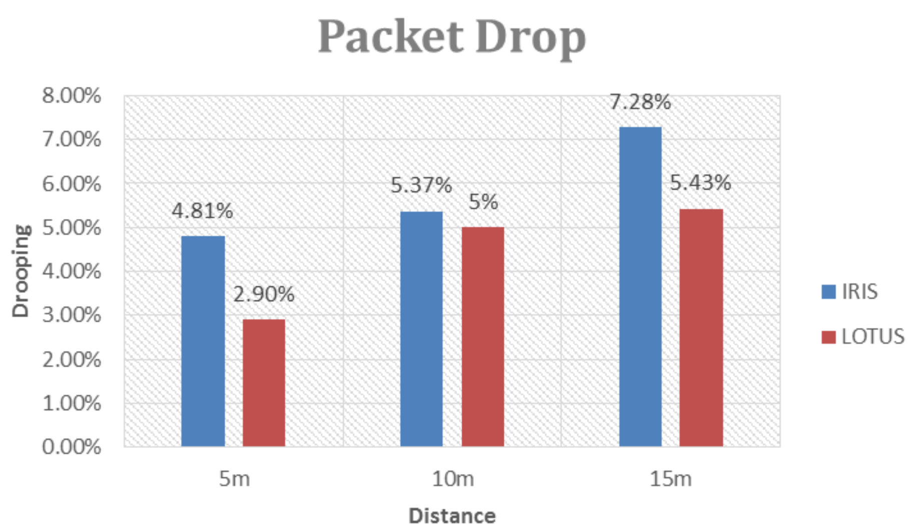


Figure 42 Packet drop for palm field Exp.

Packet dropping is one of the most important criteria that used to evaluate the performance of any system. Figure 42 shows the packet drop rate at palm field for IRIS and LOTUS motes. We can see that LOTUS lose 5.43% of its sent packet which is not good but still better than IRIS mots which lose 7.28% of all sent packets.

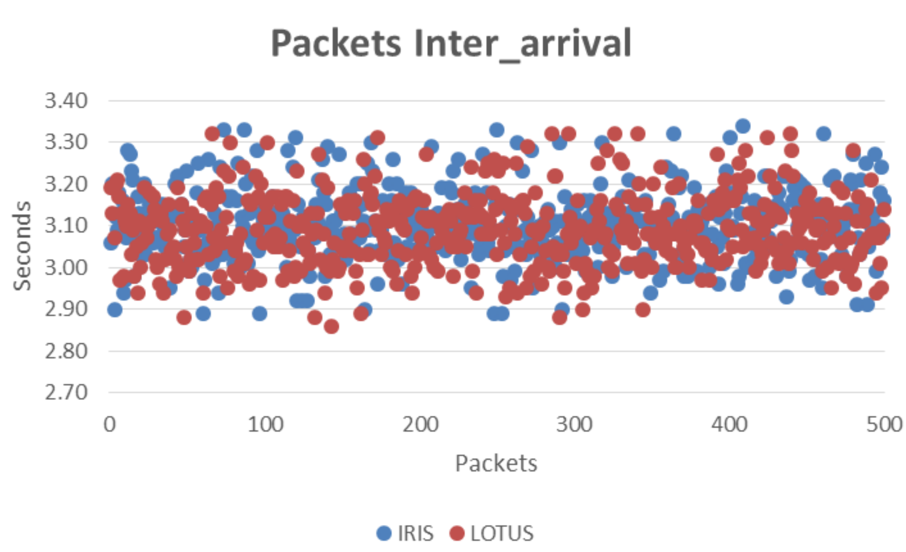


Figure 43 packet inter arrivals for IRIS and LOTUS

Figure 43 shows the packet inter-arrivals for IRIS and LOTUS where the values are between 2.85 and 3.33 seconds, but the majority of packet inter-Arrivals is around 3.11 seconds. This 0.11sec. extra time is due to the palm trees obstacles between the motes and the base station that may affected some packets.

Figures 44 and 45 shows the cumulative distribution and the probability density for the packet inter arrival in this environment respectively.

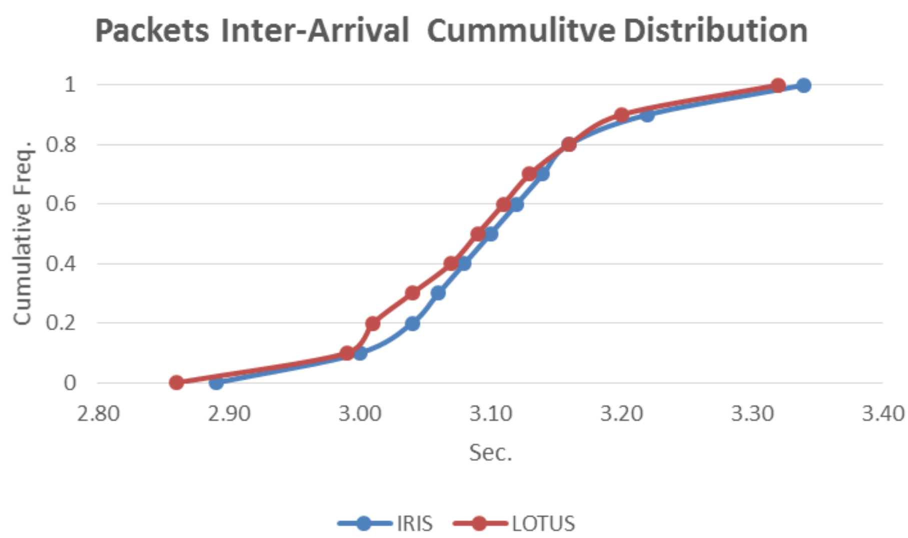


Figure 44 Inter- Arrival Cumulative Distribution for Palm field Exp.

At the end, we saw how these two generations of WSN performed at such environment where there are some obstacles. LOTUS worked better than IRIS which worked well at short distances.

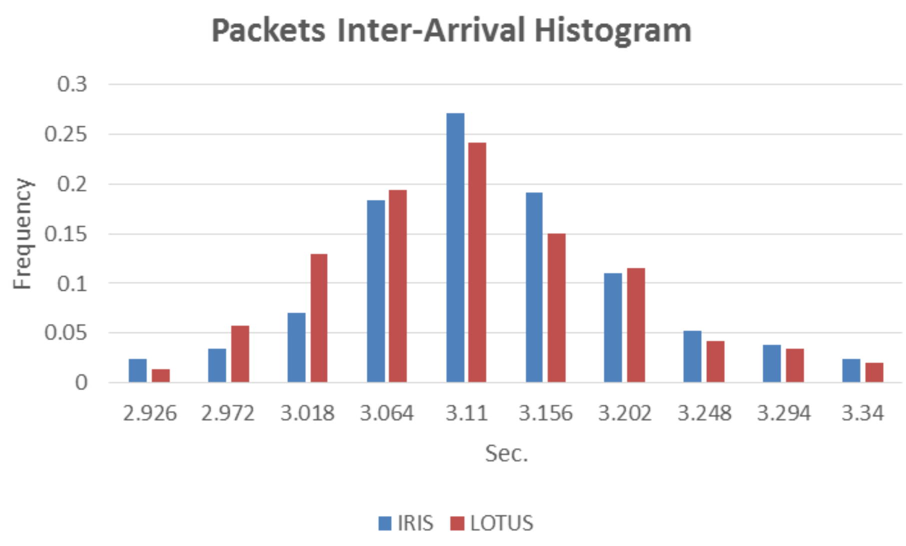


Figure 45 packets Inter-Arrivals Histogram for Palm field Exp.

5.5 Parking Experiments

These experiments have conducted at King Fahd university parking lot where it is paved with asphalt (see figure 46). The main objective of this experiments is to show how the high reflection of car metals in such environment affect the performance of WSN motes.

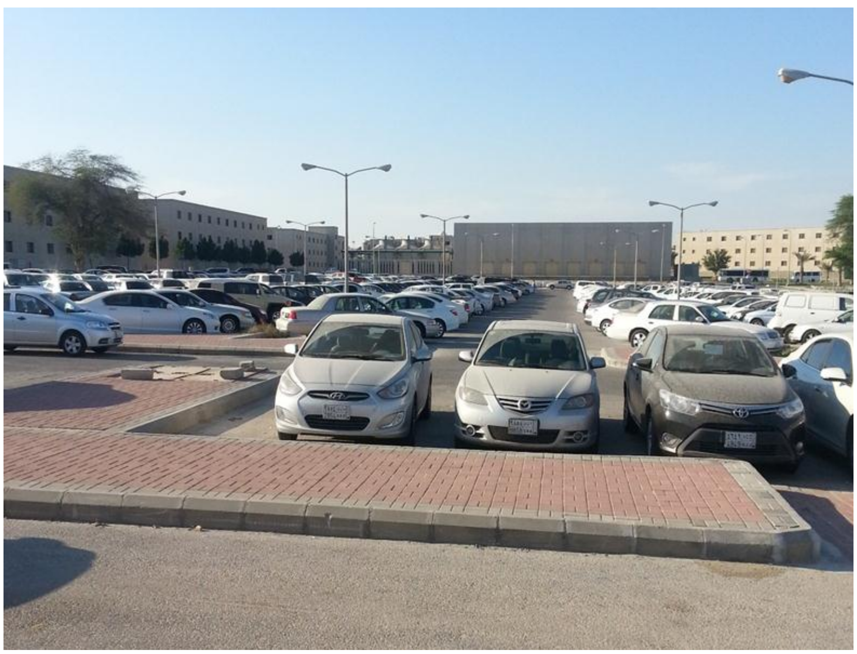


Figure 46 KFUPM Parking lot

IRIS LOTUS

Figure 47 IRIS and LOTUS Equipment for parking Exp.

5.5.1 Parking Experiments results

We spent two days doing the experiments at an active parking where there were many cars enter and other leave that parking. The overall results are summarized in table 10.

As is well known, the reflection dramatically affect the quality and strength of signals. Figure 48 shows how IRIS and LOTUS motes performed in such environment where the reflection level is high because of the surrounding metals all around the motes. We can see that RSSI of IRIS motes fall dramatically from -67dBm at 5 meters to -89dBm at 15 meters. LOTUS motes performed better at 15 meters where the RSSI level was -81dBm as shown in figure 48.

Table 10 All results for parking Exp.

IRIS 5m Parking overall average			LOTUS 5m Parking overall average		
Node	RSSI dBm	Drop	Node	RSSI dBm	Drop
1	-67	9.58	1	-66	6.76
2	-67	9.26	2	-67	7.2
3	-68	10.37	3	-66	8.1
Average	-67	9.64	Average	-66	7.35
IRIS 5m Parking overall average			LOTUS 10m Parking overall average		
Node	RSSI dBm	Drop	Node	RSSI dBm	Drop
1	-81	11.38	1	-72	10.53
2	-80	11.66	2	-73	10.89
3	-81	11.4	3	-72	9.7
Average	-81	11.48	Average	-72	10.37
IRIS 5m Parking overall average			LOTUS 15m Parking overall average		
Node	RSSI dBm	Drop	Node	RSSI dBm	Drop
1	-89	12.95	1	-80	11.53
2	-89.5	13.29	2	-81	11.54
3	-89	13.21	3	-83	12.6
Average	-89	13.15	Average	-81	11.89
IRIS Packet Inter-Arrival"Sec."			LOTUS Packet Inter-Arrival"Sec."		
Average	3.06		Average	3.07	
Confidence Interval for RSSI			Confidence Interval for RSSI		
5m	10m	15m	5m	10m	15m
± 0.15	± 0.11	± 0.09	± 0.37	± 0.39	±0.3

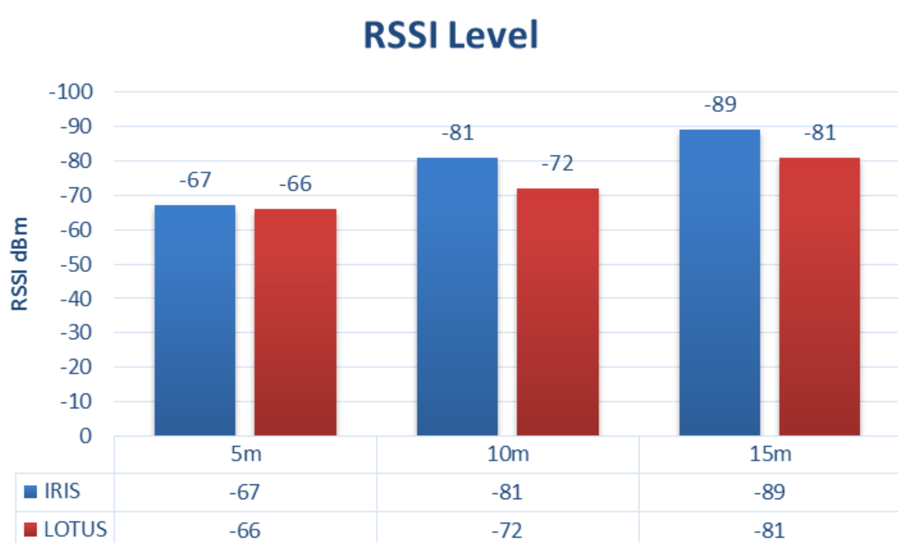


Figure 48 RSSI level for parking Exp.

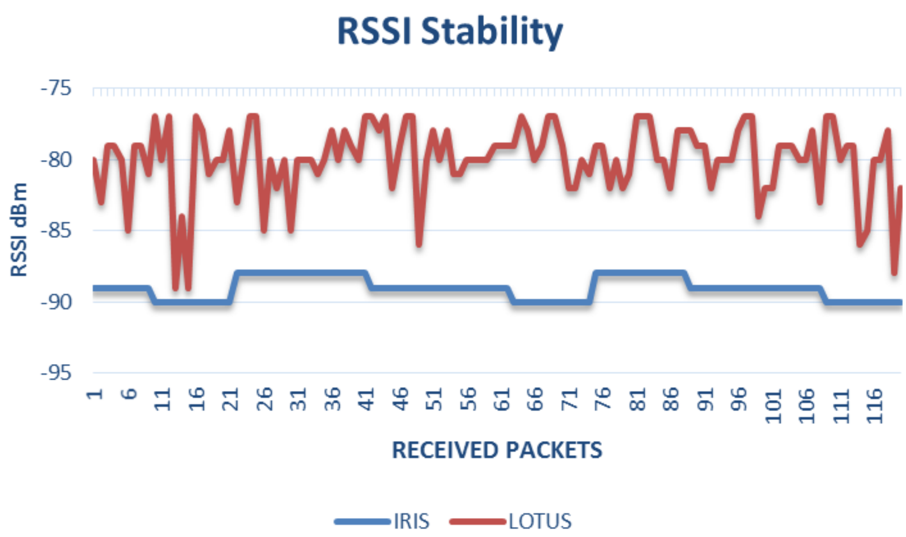


Figure 49 RSSI stability for parking Exp.

Figure 49 shows the stability of RSSI for 15 meters experiments for both IRIS and LOTUS motes at parking area. We can see how signal was volatile for the LOTUS motes, and it is more stable for the IRIS motes as shown in figure 49.

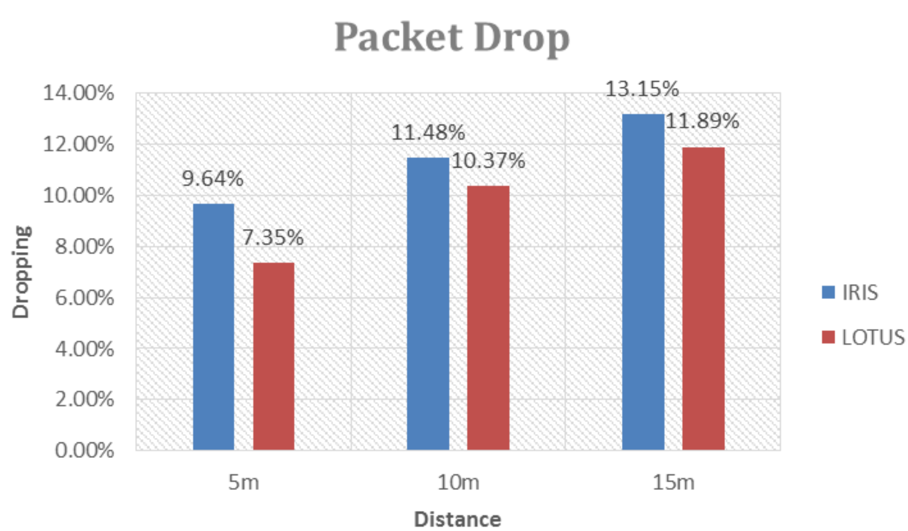


Figure 50 Packet drop for parking Exp.

Packet drop rates were excessively high as shown in figure 50. IRIS and LOTUS motes were comparable, there is no big difference between the two motes. With such high dropping rates, we can easily say that these two WSN types are not suitable at all to work in such places for the real time or critical applications.

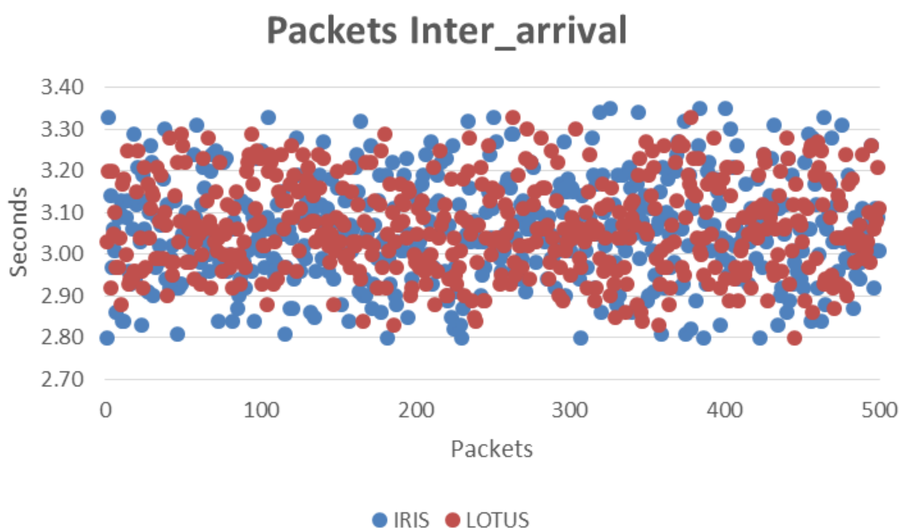


Figure 51 packet inter arrivals for IRIS and LOTUS

Packet arrivals is one of the most important criteria for the real time and critical applications where the packet should reach the destination as fast as possible in order to take the appropriate decision immediately. Figure 51 shows the packet inter-arrivals for both motes where we can see that the packet inter-arrivals is between 2.79 and 3.37 seconds. The majority of packets arrivals is around 3.07seconds but as we can see from figure 53 it was not a huge majority.

Figures 52 and 53 shows the cumulative distribution and the probability density for the packet inter arrival in this environment respectively.

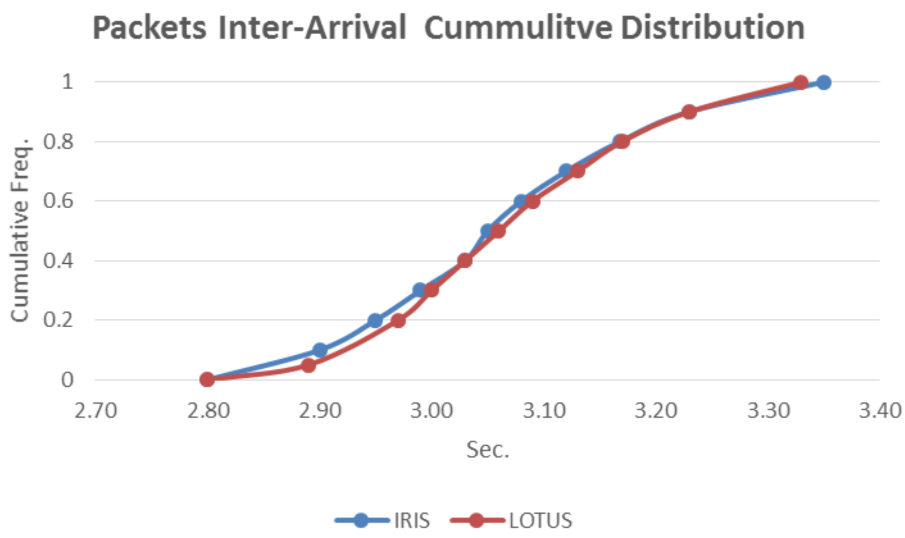


Figure 52 Inter- Arrival Cumulative Distribution for Parking Exp.

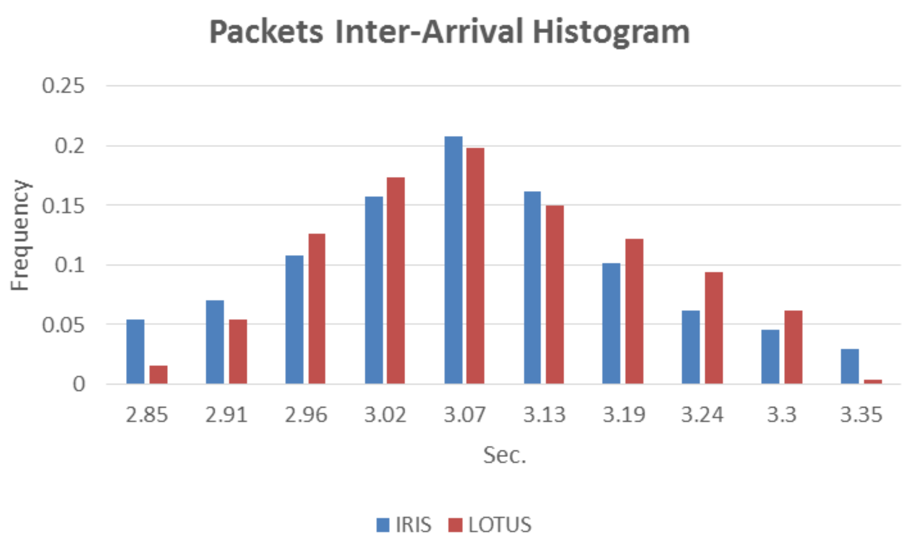


Figure 53 packets Inter-Arrivals Histogram for Parking Exp.

At the end, we can say that these motes performed in acceptable manner at short distances but these motes shows poor performance at long distances. Based on all of the above, we can say that these motes are not the best choice if we need to use a WSN technology at parking.

5.6 Under Sand Experiments

As we know WSN technology is used in multidisciplinary fields where some applications may require to use these sensor in deserts or any sandy environment where quicksand might cover that sensors. The main objective of this experiments was to test the efficacy of these sensors in the case that these sensors somehow covered by sand. In these experiments we buried our sensors at distance of 10 cm underground as reported in [34] where we used three plastic boxes to protect our sensors (see figure 54).

Figure 54 plastic box for under sand Exp.

5.6.1 Under Sand Experiments results

By using the first scenario we conducted 3 experiments for IRIS and other 3 for LOTUS, in these experiments we had to dig three small holes in the ground at different directions and distances to put our sensors into these holes instead of put them on the plastic tables (see figur54). Table 11 summarizes the overall results that obtained after conducting these experiments.

Figure 55 IRIS and LOTUS Equipment for under sand Exp.

Results related to RSSI show weakness in performance, but more importantly, that the motes were still working and sent data to the base station at short distances such as 5 meters. The RSSI level fell dramatically as we can see in (figure 56) from -82 dBm at 5 meters to -89 dBm at 10 meters for IRIS motes and we lost connectivity at 15 meters.

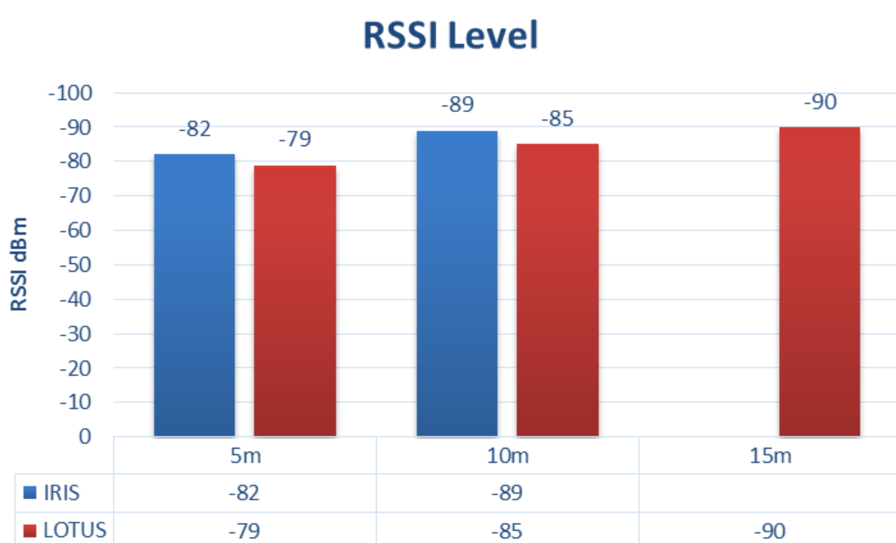


Figure 56 RSSI level for under sand Exp.

Table 11 All results for under sand Exp.

IRIS 5m U-Sand overall average		
Node	RSSI dBm	Drop
1	-81	12.83
2	-82	13.13
3	-82	13.37
Average	-82	13.11

IRIS 10m U-Sand overall average		
Node	RSSI dBm	Drop
1	-89	14.9
2	-89	15.62
3	-89	15.55
Average	-89	15.36

IRIS 15m U-Sand overall average		
Node	RSSI dBm	Drop
1		
2		
3		
Average		

IRIS Packet Inter-Arrival"Sec."		
Average	3.15	
Confidence Interval for RSSI		
5m	10m	15m
± 0.09	± 0.09	

LOTUS 5m U-Sand overall average		
Node	RSSI dBm	Drop
1	-79	9
2	-80	9.64
3	-79	10.15
Average	-79	9.6

LOTUS 10m U-Sand overall average		
Node	RSSI dBm	Drop
1	-85	13.68
2	-85	13.7
3	-85	12.36
Average	-85	13.25

LOTUS 15m U-Sand overall average		
Node	RSSI dBm	Drop
1	-90	15.1
2	-90	15.57
3	-90	15
Average	-90	15.22

LOTUS Packet Inter-Arrival"Sec."		
Average	3.14	
Confidence Interval for RSSI		
5m	10m	15m
± 0.71	± 0.2	± 0.11

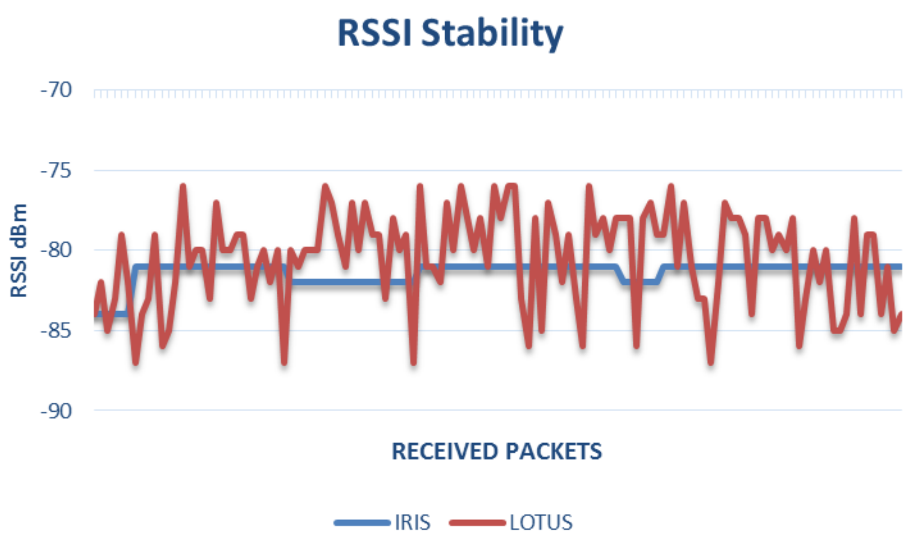


Figure 57 RSSI stability for under sand Exp.

LOTUS performed a little bit better than IRIS regarding to RSSI as an average, but as figure 57 shows the stability of RSSI is too volatile for the LOTUS and more stable for the IRIS.

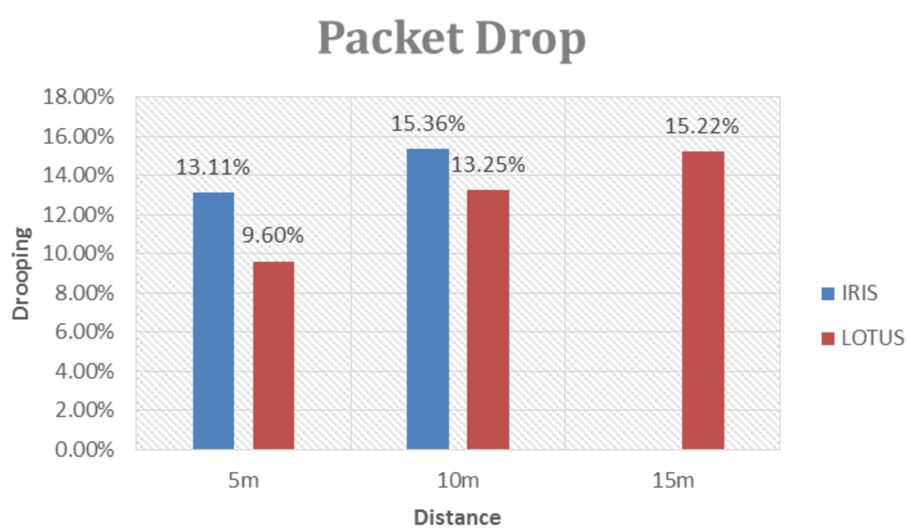


Figure 58 Packet drop for under sand Exp.

The performance of IRIS and LOTUS motes in such environment was poor as we notice from the RSSI values, that poor signal certainly will affect the packet drop rate, figure 58 shows the rate of packet drops for both motes where it is clearly too high. IRIS motes lost about 15% of the transferred packets which is huge amount for WSN systems that may affect the efficiency of any WSN system.

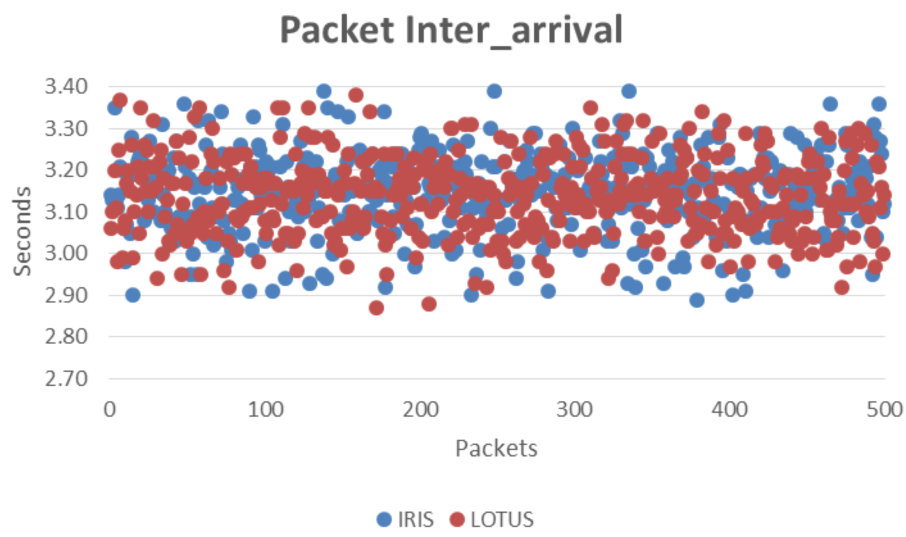


Figure 59 packet inter arrivals for IRIS and LOTUS for under sand Exp.

The second scenario was used in order to analyze the packet inter-arrivals where we had to make sure that signal used multi hop routing to reach the base station. Figure 59 shows the packet inter-arrivals for both IRIS and LOTUS motes, as we can see from the figure the packet inter-arrivals values is between 2.87 and 3.4 seconds where the majority of packet inter-arrivals is around 3.18 seconds which is an expected result given the poor performance regarding to RSSI.

Figures 60 and 61 shows the cumulative distribution and the probability density for the packet inter arrival in this environment respectively.

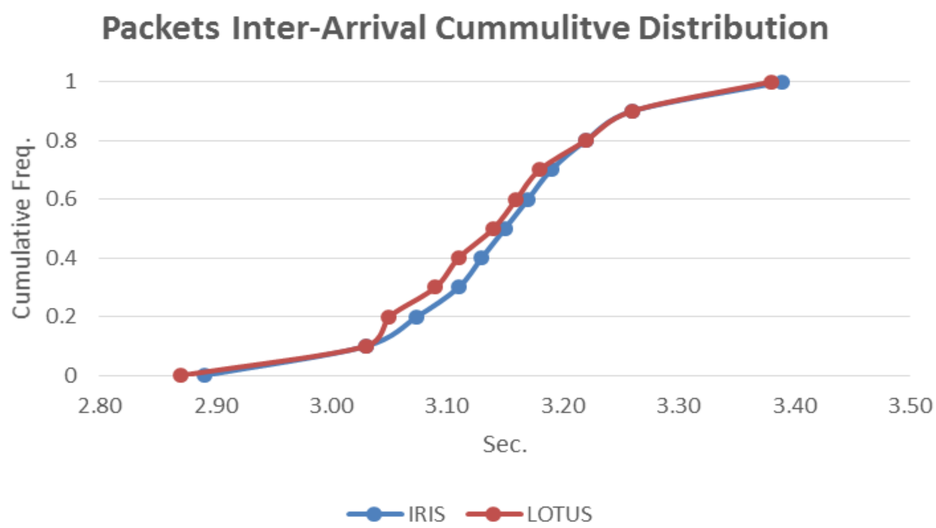


Figure 60 Inter- Arrival Cumulative Distribution for Under Sand Exp.

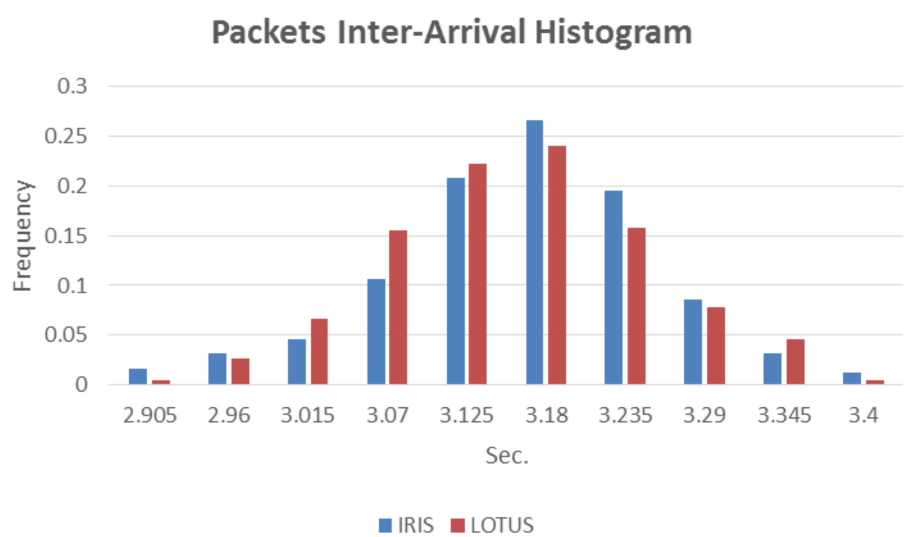


Figure 61 packets Inter-Arrivals Histogram for Under Sand Exp.

At the end, it is obvious that these two types of WSN are not intended to perform at such environment especially at large distances. All measurements were not encouraging to use these two WSN types under sand.

5.7 Under Soil Experiments

Wireless sensor networks applications can support farmers to avoid damages to their crops or even increasing crop production by monitoring relevant parameters, for example, soil moisture and air temperature, and to transmit data wirelessly to the farmer location, so that appropriate measures can be adopted. In these experiments we aimed to test these two type of WSN by buried the motes under dry soil at a distance of 10 cm underground where we used a plastic boxes to protect our motes (see figure 62).

Figure 62 plastic box for under soil Exp.

Figure 63 IRIS and LOTUS Equipment for under soil Exp.

5.7.1 Under Soil Experiments results

In these experiments we follow the same scenario that we followed when we did the under sand experiments. Many people confuse sand and soil as being one in the same. The difference between sand and soil is that soil has pores that allows for water to be held. Sand on the other hand is loose and does not have any pores. Table 12 shows all collected results for these experiments.

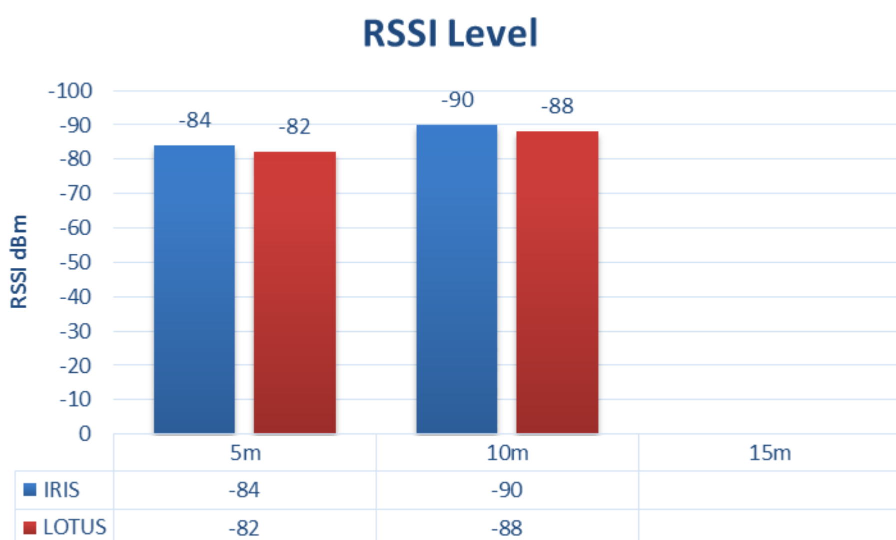


Figure 64 RSSI level for under soil Exp.

Table 12 All results for under soil Exp.

IRIS 5m U-Soil overall average		
Node	RSSI dBm	Drop
1	-84	15.33
2	-84	15.61
3	-84	15.92
Average	-84	15.62
IRIS 10m U-Soil overall average		
Node	RSSI dBm	Drop
1	-90	18.97
2	-89	19.29
3	-90	19.32
Average	-90	19.19
IRIS 15m U-Soil overall average		
Node	RSSI dBm	Drop
1		
2		
3		
Average		
IRIS Packet Inter-Arrival"Sec."		
Average	3.18	
Confidence Interval for RSSI		
5m	10m	15m
± 0.1	± 0.07	

LOTUS 5m U-Soil overall average		
Node	RSSI dBm	Drop
1	-82	13.16
2	-81	13.72
3	-82	12.95
Average	-82	13.28
LOTUS 10m U-Soil overall average		
Node	RSSI dBm	Drop
1	-88	14.98
2	-89	15.57
3	-88	13.66
Average	-88	14.74
LOTUS 15m U-Soil overall average		
Node	RSSI dBm	Drop
1		
2		
3		
Average		
LOTUS Packet Inter-Arrival"Sec."		
Average	3.19	
Confidence Interval for RSSI		
5m	10m	15m
± 0.25	± 0.24	

Unlike sand, soil is more compressed which does not allow the signal to pass through to get to the destination. Figure 64 shows the RSSI level at 5, 10 and 15 meters for both motes where we can see the values were too low for 5 and 10 meters. The connectivity was lost at 15 meters for both IRIS and LOTUS motes as we can see from the figure above.

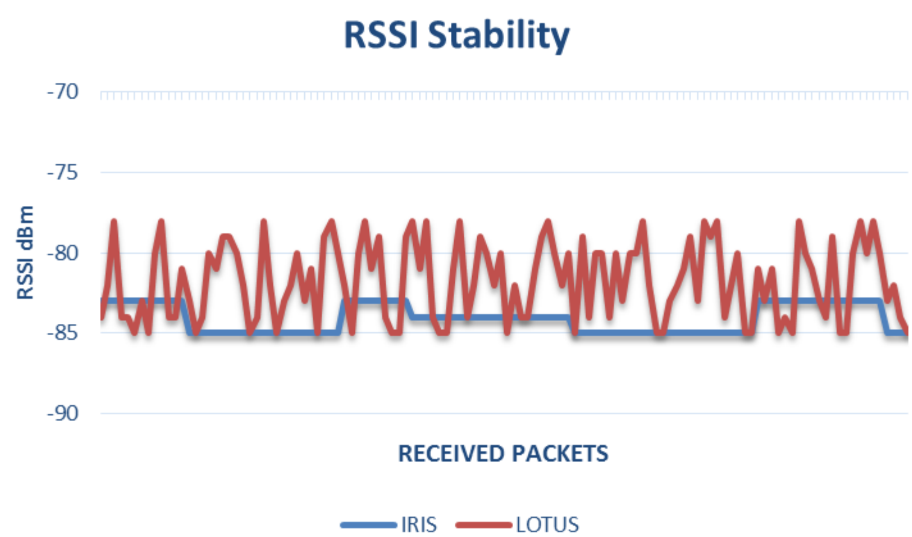


Figure 65 RSSI stability for under soil Exp.

As usual, we take a look at the RSSI stability for one IRIS mote and one LOTUS mote at same distance to show the sensitivity of the signal to the surrounding environment. Figure 65 shows the RSSI stability for IRIS and LOTUS motes. The RSSI for IRIS is more stable than LOTUS RSSI which mean LOTUS motes are more sensitive than IRIS to the surrounding environment.

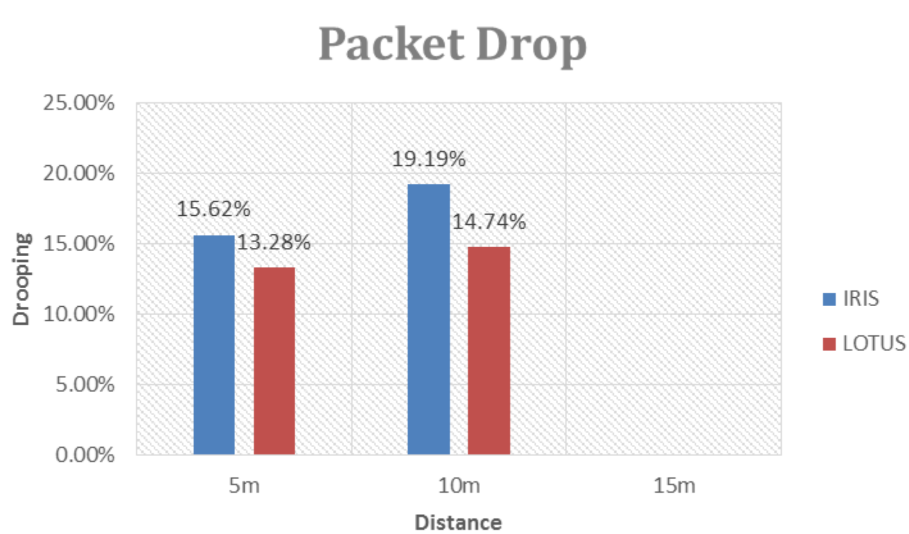


Figure 66 Packet drop for under soil Exp.

The poor performance for both motes in these experiments reflected at the packet drops rates as shown in figure 66. IRIS motes lost about 20% of the transferred packets at 10 meters distance, this rate is absolutely unacceptable for any WSN system.

Using the second scenario, we tried to analyze the packet inter-arrivals where we dug three small holes in a row and put our sensors inside plastic boxes for protection and then buried them by soil. During the monitoring we made sure that mote 3 connected to mote 2 and mote 2 connected to mote 1 and then to the base station as explained in second scenario.

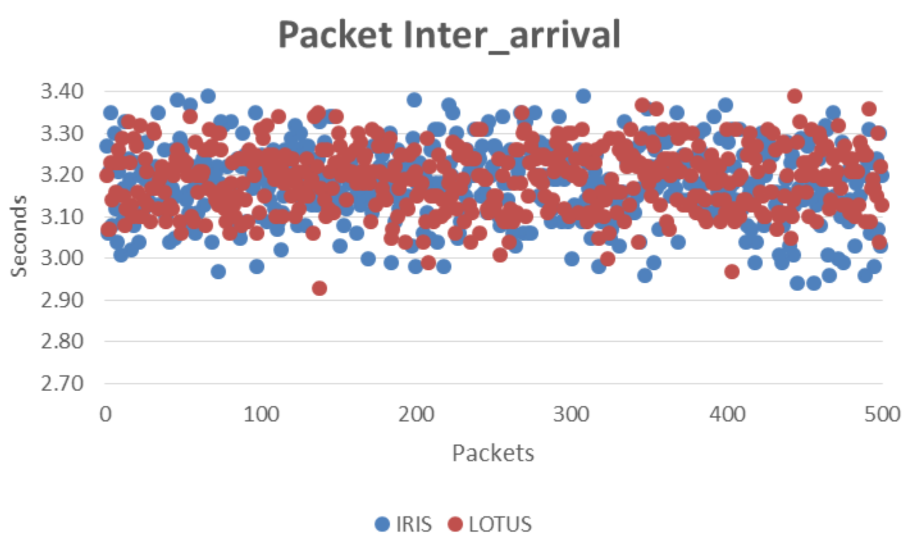


Figure 67 packet inter arrivals for IRIS and LOTUS for under soil Exp.

Figure 67 shows the packet inter-arrivals for both IRIS and LOTUS motes, we can note that the values were between 2.93 and 3.4 seconds where the majority of packet inter-arrivals is 3.21 seconds which is the largest result among the all experiments due to the weak performance of the IRIS and LOUS motes in this environment.

Figures 68 and 69 shows the cumulative distribution and the probability density for the packet inter arrival in this environment respectively.

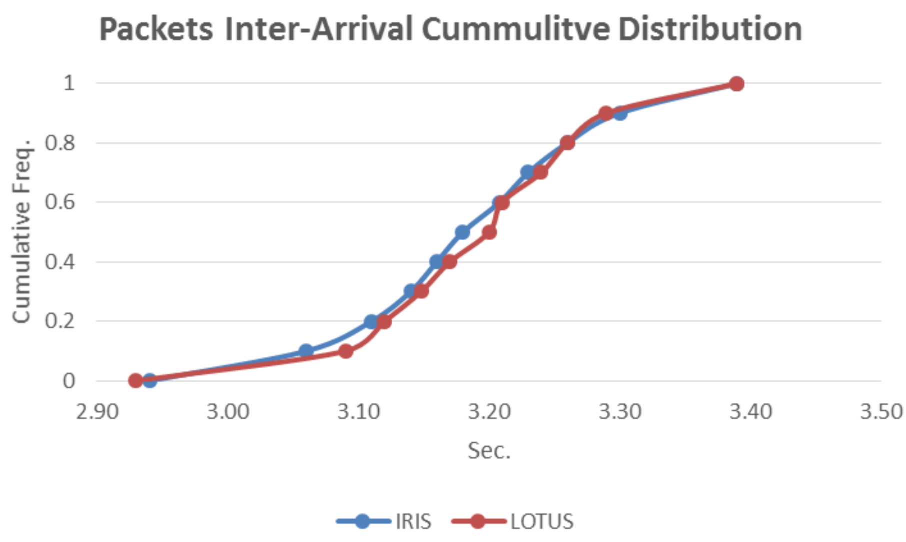


Figure 68 Inter- Arrival Cumulative Distribution for Under Soil Exp.

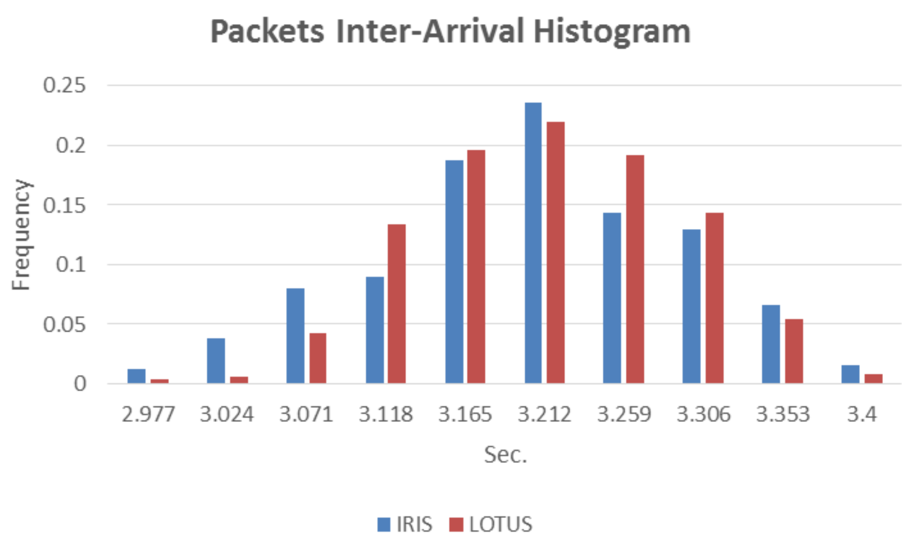


Figure 69 packets Inter-Arrivals Histogram for Under Soil Exp.

At the end of under soil experiments, it is clear that these two types of WSN are not designed to work in these circumstances. Consequently, we experimentally proved that soil has significant impact on signal transfer as we saw earlier in this section.

5.8 Valley Experiments

The motes at all previous experiments were put at the same level from the ground where we used four plastic tables entirely similar, one for the base station and the other three for the motes in order to ensure that all devices are located at same level from the ground. The main objective of these experiments is to figure out how these two WSN motes will perform when these motes are located at different levels from the ground (see figure 70).

Figure 70 Valley Exp.

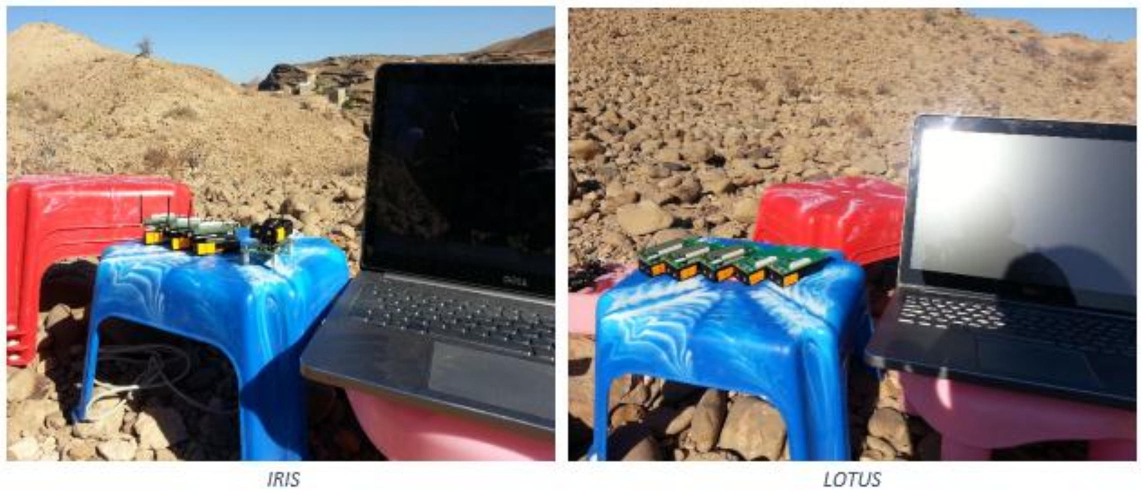


Figure 71 IRIS and LOTUS Equipment for valley Exp.

5.8.1 Valley Experiments results

These experiments were conducted in a small valley where the ground was sloping. We follow the same two scenarios that used for other experiments, the only difference here was that the motes were not placed on the same level horizontally. Table 13 summarizes the values resulting from these experiments.

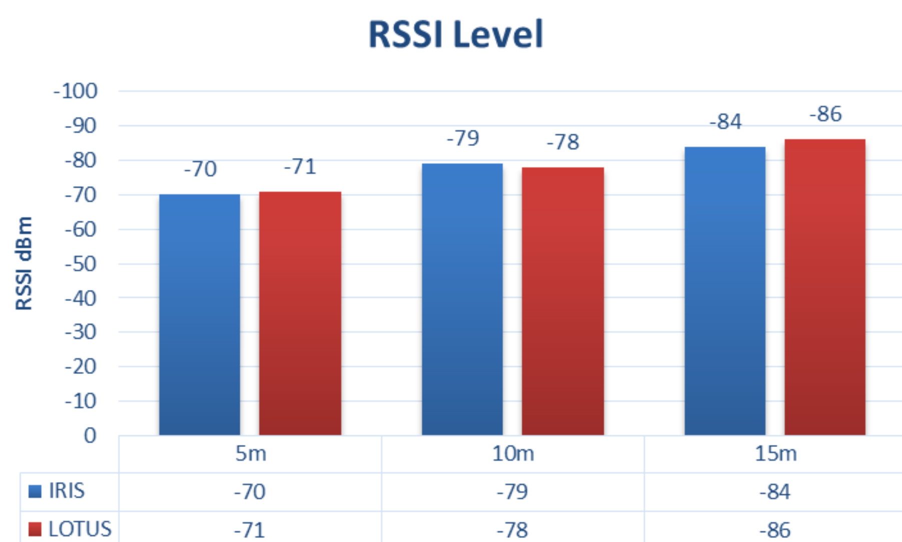


Figure 72 RSSI level for valley Exp.

Table 13 all results for valley Exp.

IRIS 5m Valley overall average		
Node	RSSI dBm	Drop
1	-81	8.64
2	-62	5.67
3	-67	6.96
Average	-70	7.1
IRIS 10m Valley overall average		
Node	RSSI dBm	Drop
1	-75	7.22
2	-78	8.1
3	-85	9.14
Average	-79	8.15
IRIS 10m Valley overall average		
Node	RSSI dBm	Drop
1	-81	8.88
2	-89	10.91
3	-82	8.78
Average	-84	9.52
IRIS Packet Inter-Arrival"Sec."		
Average	3.09	
Confidence Interval for RSSI		
5m	10m	15m
± 0.81	± 0.45	± 0.4

LOTUS 5m Valley overall average		
Node	RSSI dBm	Drop
1	-74	7.55
2	-68	5.87
3	-71	6.52
Average	-71	6.65
LOTUS 10m Valley overall average		
Node	RSSI dBm	Drop
1	-75	14.81
2	-74	14.2
3	-84	17.64
Average	-78	15.55
LOTUS 15m Valley overall average		
Node	RSSI dBm	Drop
1	-84	19.15
2	-89	21.68
3	-84	17.39
Average	-86	19.4
LOTUS Packet Inter-Arrival"Sec."		
Average	3.10	
Confidence Interval for RSSI		
5m	10m	15m
± 0.44	± 0.54	± 0.36

In this experiment, there were great contrast in the results depending on whether the mote higher or lower than the base station.

Table 13 shows all results for all motes at different distances, if we focused on the results of the IRIS 5 meters experiment, we will see that the RSSI value for mote 1 is -81 while the other two motes reach -62dBm, as shown in the table, that's because of the location of that mote where it was lower than the base station. Table 13 shows the confidence interval of RSSI for both systems which giving us a clear idea how good was the RSSI average.

Figure 72 shows the overall average for all three motes, we can see that IRIS motes performed very well at this environment. There was a slight advantage for LOTUS at 5 meters distance, but then that advantage turned to the IRIS motes at 10 and 15 meters as shown in figure 72.

Figure 73 shows the stability of RSSI for IRIS and LOTUS motes at valley environment, it is clear that RSSI affected especially for the LOTUS we can see how volatile was the RSSI at this environment.

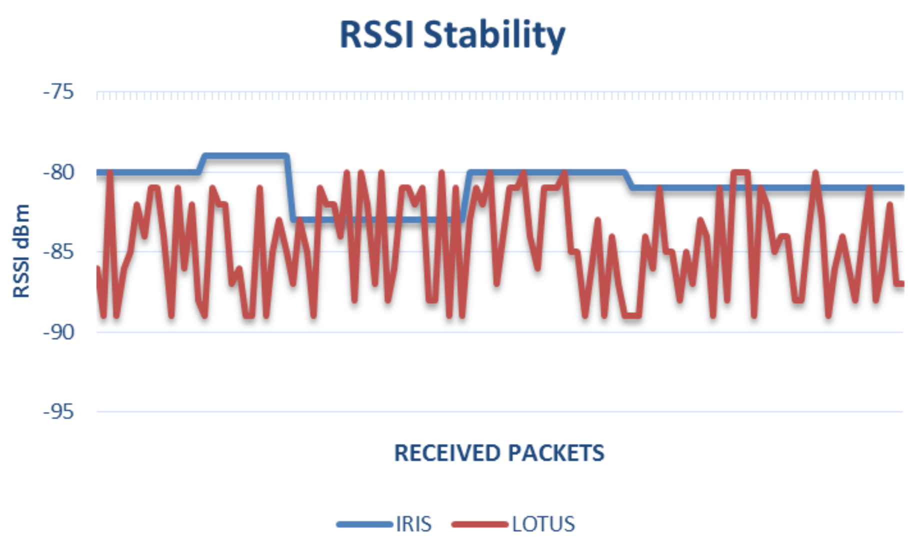


Figure 73 RSSI stability for valley Exp.

IRIS motes showed very good performance at these experiments, figure 74 shows the packet drops rate for the two WSN types. From the figure we can see the great superiority of the IRIS motes regarding to packet lose especially at 10 and 15 meters. We think that the IRIS antenna played great role in this experiments, where LOTUS antenna is integrated with the device as shown in figure 7.

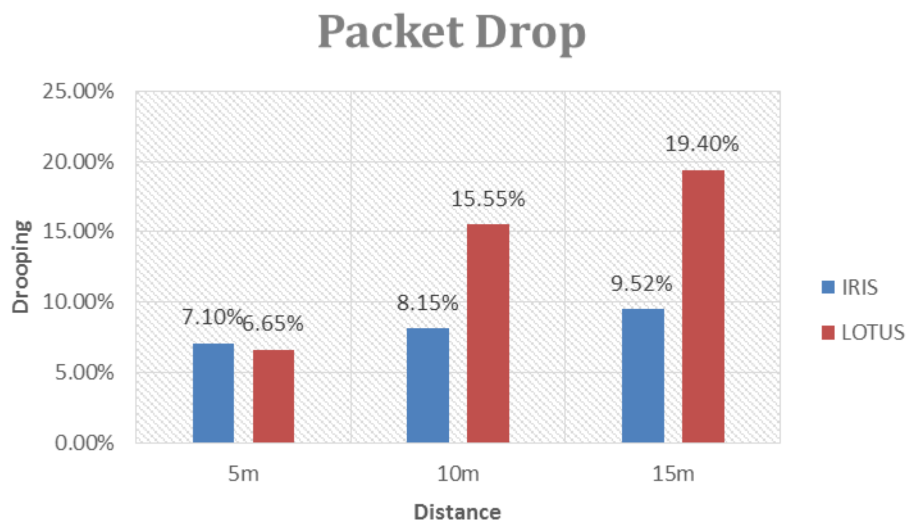


Figure 74 Packet drop for valley Exp.

LOTUS motes performed poorly at this environment based on the results, it lost about 20% of the transferred packets at 15 meters distance as we can see from the figure 74 which is a very high rate that certainly will affect the efficiency of any system that uses this motes.

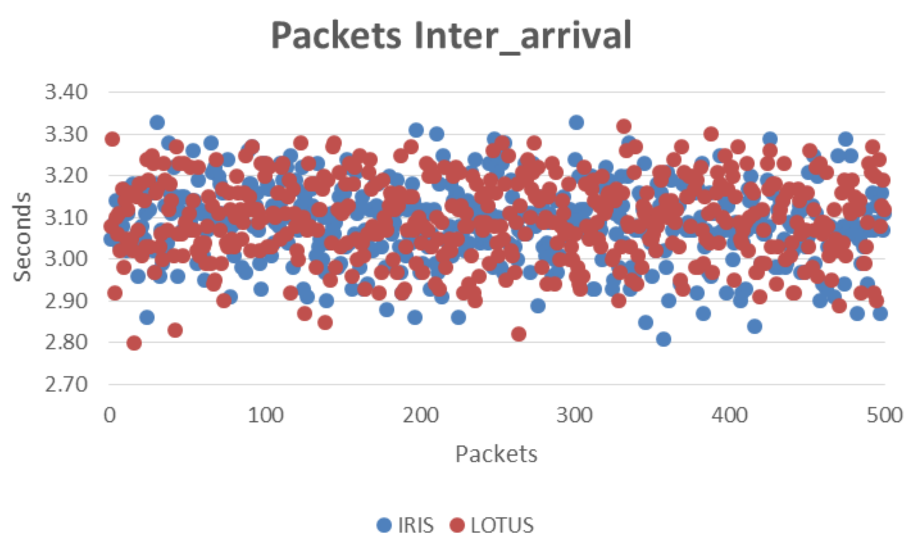


Figure 75 packet inter arrivals for IRIS and LOTUS for valley Exp.

Figure 75 shows the packet inter-arrivals, where we used the second scenario which is based on the multi hop routing. As we notice the values are between 2.79 and 3.34 seconds, where the majority of these values was 3.12 seconds.

Figures 76 and 77 shows the cumulative distribution and the probability density for the packet inter arrival in this environment respectively.

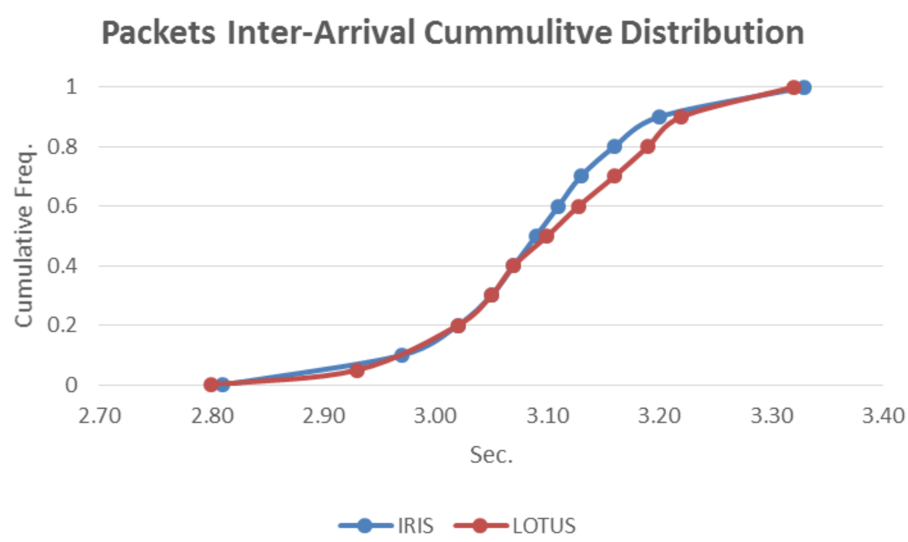


Figure 76 Inter- Arrival Cumulative Distribution for Valley Exp.

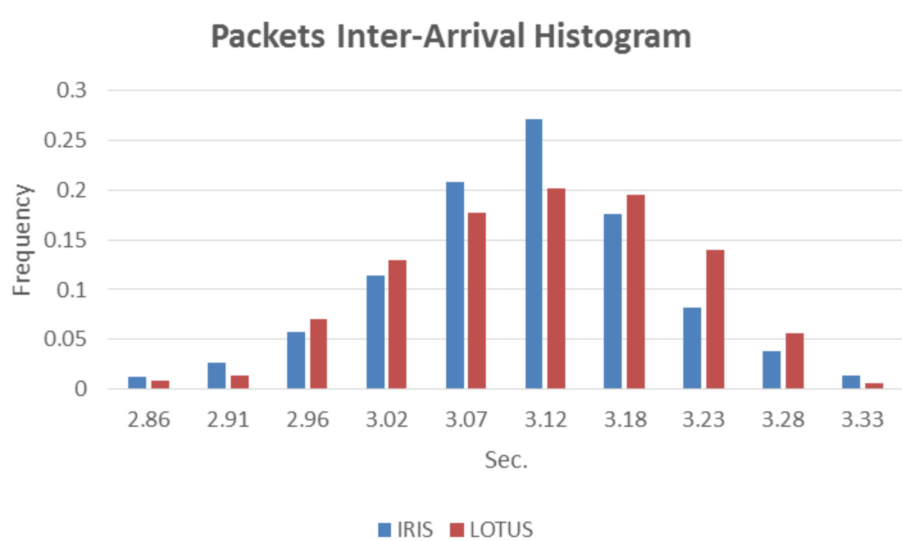


Figure 77 packets Inter-Arrivals Histogram for Valley Exp.

At the end and based on all the results, we can say that the LOTUS motes is not good to work at similar situations and environments, but on the other hand, IRIS performed very well at this experiments which means it is more capable and efficient than LOTUS at this environment.

5.9 Power Consumption

In this section we will investigate the WSNs' power consumption for IRIS and LOTUS wireless motes. In electrical engineering, power consumption often refers to the electrical energy over time supplied to operate an electrical appliance. Two random motes were selected (one IRIS and one LOTUS) and tested under the HP mode using a 3-second data message interval (DMI). Each mote was powered with two Maxell LR6/GD 1.5V AA Alkaline batteries (see figure 78) where we used 6 batteries for each mote which means we ran this test three times and then got the average.

Figure 78 Maxell LR6/GD 1.5V AA Alkaline batteries

For this experiment, we put our motes close to the base station on same desktop as shows in figure 79. The starting voltage is based on the earliest stable battery level recorded in the mote's data packets. The ending voltage is the last recorded battery level received by the mote before transmissions stopped.

Figure 79 power efficiency Exp.

A clear idea of the power consumption is given in figure 80, we can see that IRIS and LOTUS motes consumed almost the same amount of power.

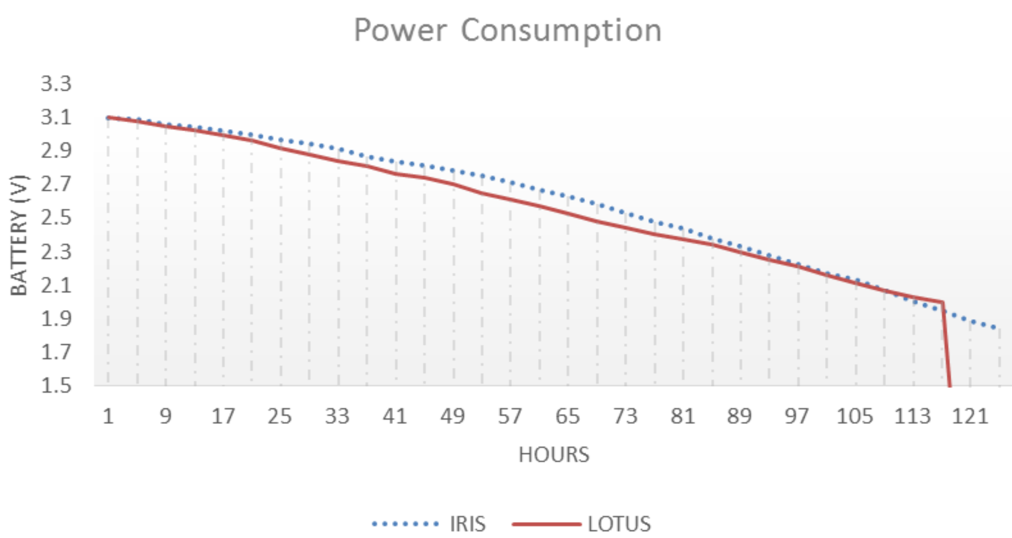


Figure 80 power efficiency for IRIS and LOTUS motes

The recommended operating voltage for motes is 3.6–2.7 V [24], however it has been shown that the IRIS mote can continue to collect data down to 1.7 V and LOTUS mote can continue to collect data down to 2 V(see figure 80, 81).

Figure 81 the last recorded battery level received by the motes

5.10 Overall Performance Comparison

In the previous sections we review the performance of IRIS and LOTUS wireless motes for each situation individually. In this section, we will review the performance of the wireless motes in all environments which gives us a clear idea of the efficiency of these motes in those environments.

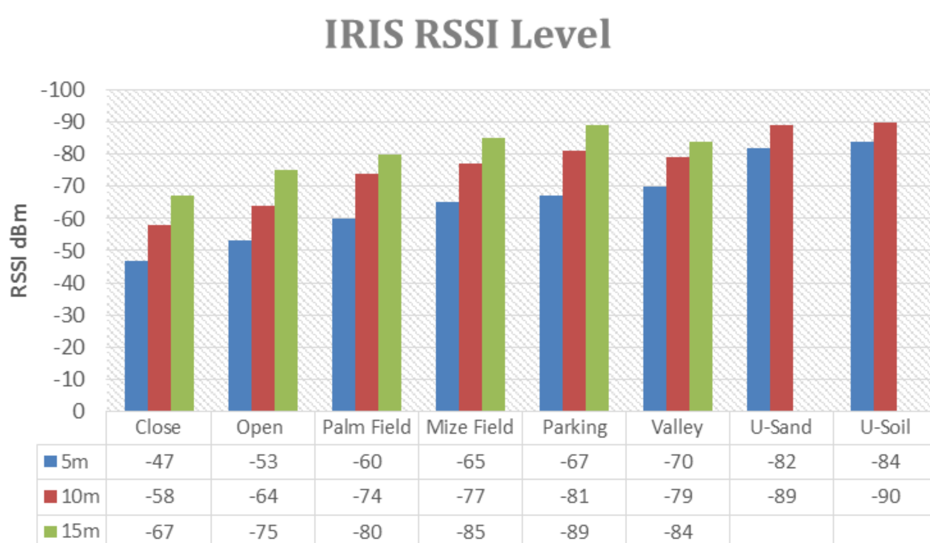


Figure 82 RSSI level for IRIS motes in all environments

Figures 82, 83 show the RSSI level for IRIS and LOTUS wireless motes in all environments, we can see that closed area environments was the perfect area for both type of motes to perform, perhaps due to that signal does not face any obstacles or any weather conditions to reach the destination.

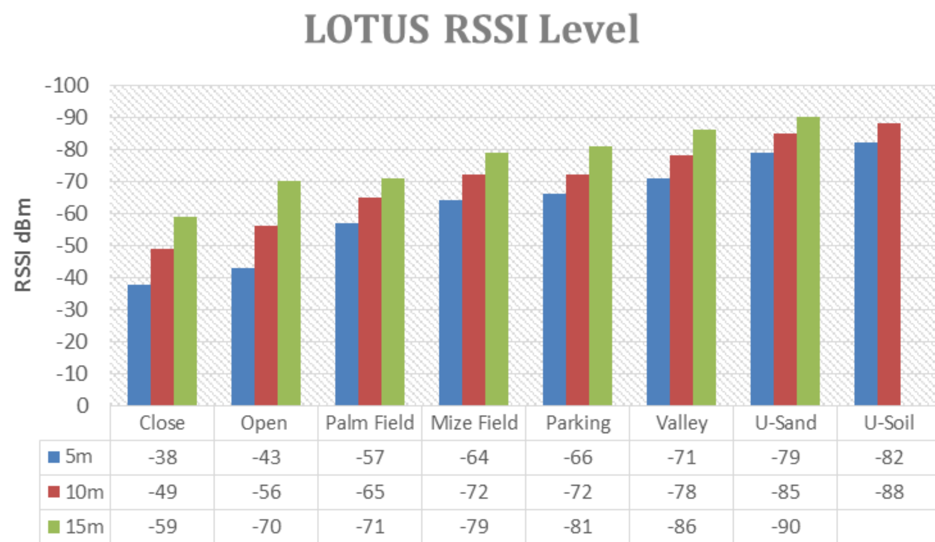


Figure 83 RSSI level for LOTUS motes in all environments

Open area is also one of the best environment that wireless motes performed at where there were no obstacles but the weather conditions such as wind and dust.

Palm field and maize field are containing obstacles that will certainly affect the signal strength, figures above show the significant impact of these obstacles, compared with open and close areas RSSI. The RSSI level of maize filed is lower than RSSI level of palm field, this indicate that the density of plants have a major impact on RSSI for both wireless motes. At the parking experiments we can see the poor performance for both IRIS and LOTUS wireless motes. This performance due to the surrounding metals that reflect the signals. The valley experiments revealed how weak performance of these WSN motes at uneven environment. For the last two experiments where we buried our motes under sand and soil, the performance was very weak as we see in the figures 82, 83. These wireless motes are not made to work underground and as a results of these experiments we do not recommend using IRIS or LOTUS wireless motes under the sand and soil.

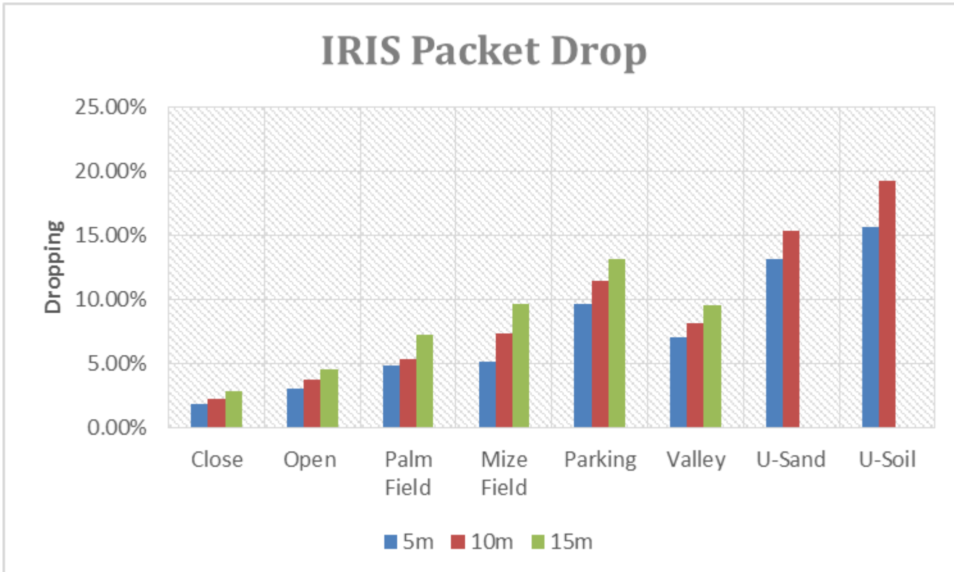


Figure 84 packet drops for IRIS motes in all environments

Packet drops rate is one of the most important criteria that determine the efficiency of the whole system. As we can see from figures (84, 85), we can see an inverse relationship between the RSSI and packet drops, the high the RSSI, the less the packet dropped for IRIS and LOTUS motes. From the figure 84 we see that motes loss too much packets regarding to under soil experiments then comes under sand. The best environment for packet losing was the close area environment.

Figure 85 shows the packet drops for LOTUS in all environments, it is obvious that LOTUS motes did not perform well at valley, under soil and under sand environments depending on the packet drops results. This is due to the nature of these environments where there are a lot of obstacles between the transmitter and receiver.

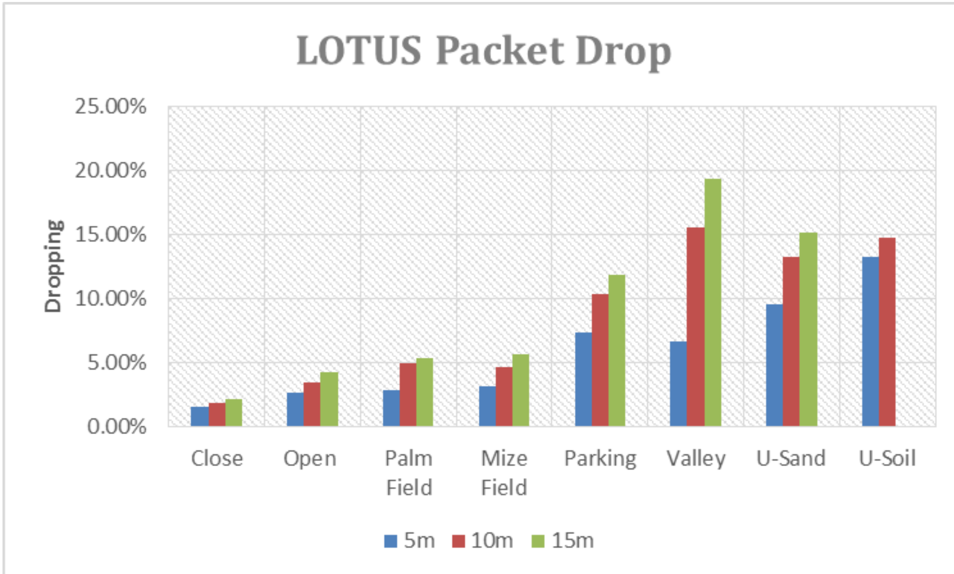


Figure 85 packet drops for LOTUS motes in all environments

Figure 86 shows the packet inter-arrivals average for IRIS and LOTUS wireless motes in all tested environments.

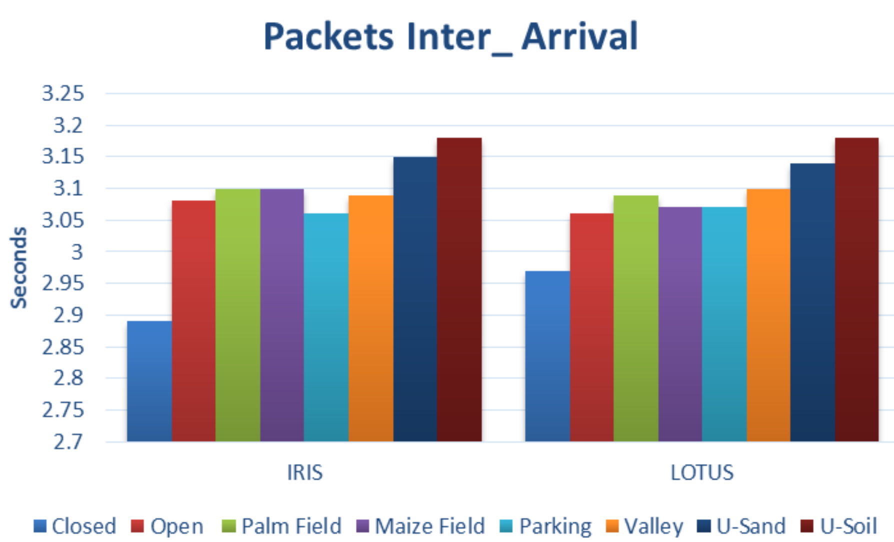


Figure 86 packet transfer delay for IRIS and LOTUS motes in all environments

The majority of packets sent from the motes that located under soil require a longer time to reach the base station while it is reach the destination faster at close area. These results give us a clear idea if we need to use one of the wireless motes that we investigated in such environments.

Based on these results we can decide whether these wireless motes meet the application requirement that we build or not. The real time and critical applications does not accept long time to receive packets and some applications consider it as an error.

CHAPTER 6

CONCLUSION AND FUTURE WORK

In this final chapter, we will conclude this study by summarizing our work and recommendations, as well as discuss the suggestions for future works.

6.1 Conclusion

In this section, we will review the contributions that resulted from the conducted experiments. We were aware that the medium and distance affect any wireless communication, but what was the effects of different medium on the wireless communication? Through this study, we answered this question by conducting a series of experiments in eight different environments using IRIS and LOTUS wireless motes.

The results gathered from the experiments conducted on a real test-bed had been compared and analyzed, in order to evaluate the performance of IRIS and LOTUS wireless motes. Who has the interest to use one of these two wireless motes, will find our results helpful and may assist him to make the right decision whether to use it or not by comparing his application requirements and the performance of these motes in similar environment.

IRIS and LOTUS motes performed perfectly in some environments and poorly in others, these two wireless sensor generations are good choice for close and open areas, where they can work very well for long-distance, that's because at these areas the signals do not face any obstacles that would cause any kind of noise or interference.

In palm and maize fields, the performance of IRIS and LOTUS wireless motes was unstable where it was acceptable at short distance, such as 5 meters, but it was poor at 15 meters. Nevertheless, IRIS and LOTUS motes shows substantially a better performance in palm field environment than maize field, this is due to the density of plants, where it is higher in maize field which might block or distortion the signal.

The signal generated by these motes is excessively sensitive to the surrounding environment which clearly shows from the results of under sand and under soil experiments. The performance of IRIS and LOTUS wireless motes at such environments was very weak, where we lost the connection at 15 meters. Based on the poor performance, we do not support the use of these motes underground.

In the parking, the signals can be reflected, refracted or diffracted due to the interaction with cars and the media in which they travel to reach the destination. IRIS and LOTUS wireless motes showed wobbling performance at this environment, which shows the sensitivity of the signal for metallic materials. In such environment, a simple tuning motes places can significantly increase the performance of these motes. Accordingly, it's possible to use these wireless motes in parking, but we need to be careful where to put those motes.

The last experiment environment was the valley, where IRIS and LOTUS motes were located at different levels from the ground. Overall results were surprising as the motes did not work well especially when the mote lower than the base station. We recommend that the spacing between the motes does not exceed 5 meters.

As an additional simple experiment, we examined the power consumption for IRIS and LOTUS wireless motes. IRIS wireless motes shows slightly a better performance in terms of the power consumption and battery life time than LOTUS motes.

In conclusion, our work provides valuable information that will help anyone who wants to use wireless sensor technology in similar environments. These results and information may save a lot of time and effort to the decision makers when it's come to select one of the two wireless motes generations.

6.2 RECOMMENDATIONS

As recommendations out of this study, we can list some points as follow:

- IRIS and LOTUS motes are recommended to be used in closed areas where no obstacles at short or long distances.
- IRIS and LOTUS motes are recommended to be used in open areas where no obstacles but the weather conditions at short or long distances.
- IRIS and LOTUS motes are recommended to be used in palm and maize fields at short distances such as 5 meters between the motes.
- IRIS and LOTUS motes are not recommended to be used underground.
- IRIS motes are recommended to be used at sloping environments at short distance.
- IRIS and LOTUS motes are recommended to be used in parking at short distances, but we need to be careful where to put those motes.
- It is always important to specify our application requirements before we chose the WSNs system.

- These two WSNs systems are not recommended to be used for real time or critical applications.

6.3 Future Work

There are many suggestions that could be made for future work to expand and improve this study:

- Doubling the number of used motes, instead of 3 motes we will use 6 motes, to see the interference impact on the performance.
- Apply the same approach taken in this thesis and implement it with different data rate in order to find out how data transfer rate might affect the performance of the motes.
- Collect data from a mobile sensor nodes instead of static nodes.
- Implement our scenarios in more active situations, whether human activity or machinery, to figure out how much the surrounding activities affect the motes performance.
- Conduct the same study to determine the effect of weather on the performance efficiency such as rain, wind, dust, fog and snow.
- Expand the study to include wireless sensor motes other than IRIS and LOTUS, such as CRICKET, TELOSB and MICAz.

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APPENDIX 1

INITIAL SETUP

In order to install MoteView and LotusView the filing system on the hard disk must be NTFS. For these two applications to run the following additional components are required:

- PostgreSQL 8.4 database service
- PostgreSQL ODBC driver
- Microsoft .NET 1.1 framework

The installation files for these components are included on the MoteView and LotusView installation CDs.

Installation Steps

The installation steps for both MoteView and LotusView are almost identical, therefore we will explain it only once as follow:

Shut down all the programs running on your computer.

1. Insert the *MoteView* or *LotusView Support* CD into the computer's CD drive.
2. Double-click on ***MoteViewSetup.exe*** from *MoteView* folder or ***LotusViewSetup.exe*** from *LotusView* folder.
3. At the Welcome to the MoteView or *LotusView* Setup Wizard window, click next>.
4. Select the desired installation directory, then click Next> (see figure 87 and 88).

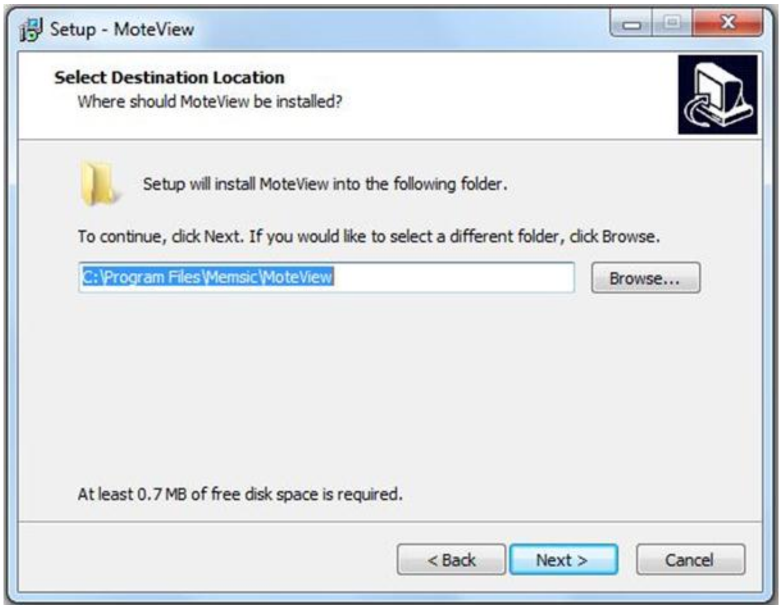

Figure 87 Selecting destination location for MoteView

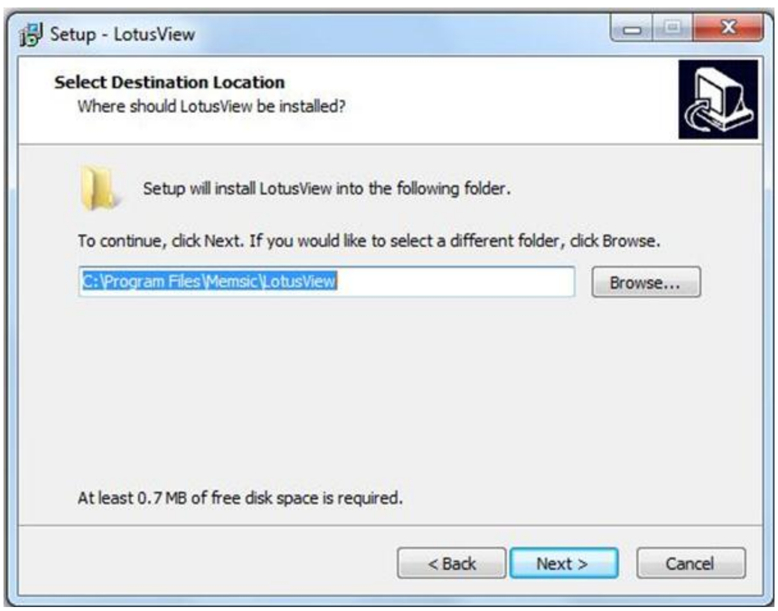

Figure 88 Selecting destination location for LotusView

5. Select the desired Start Menu folder name and click Next> (see figure 89 and 90).

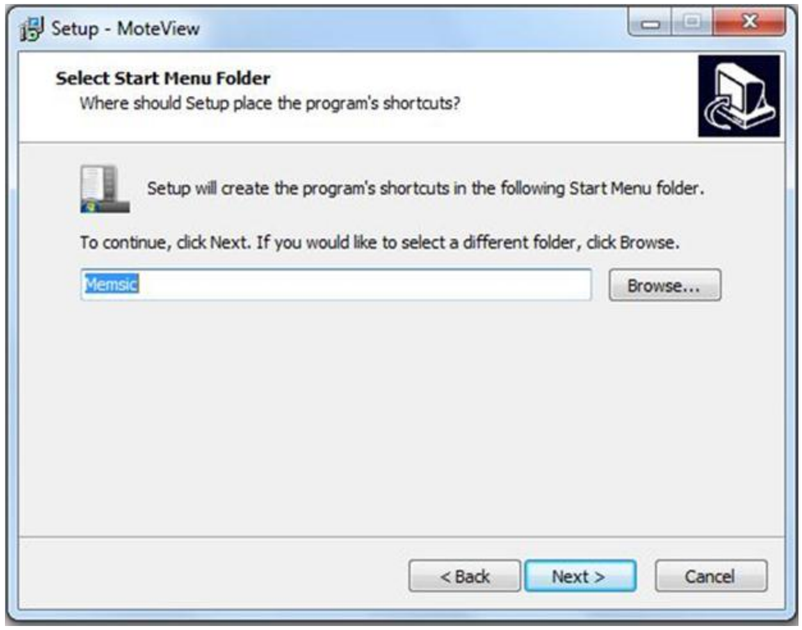

Figure 89 Selecting start menu folder for MoteView

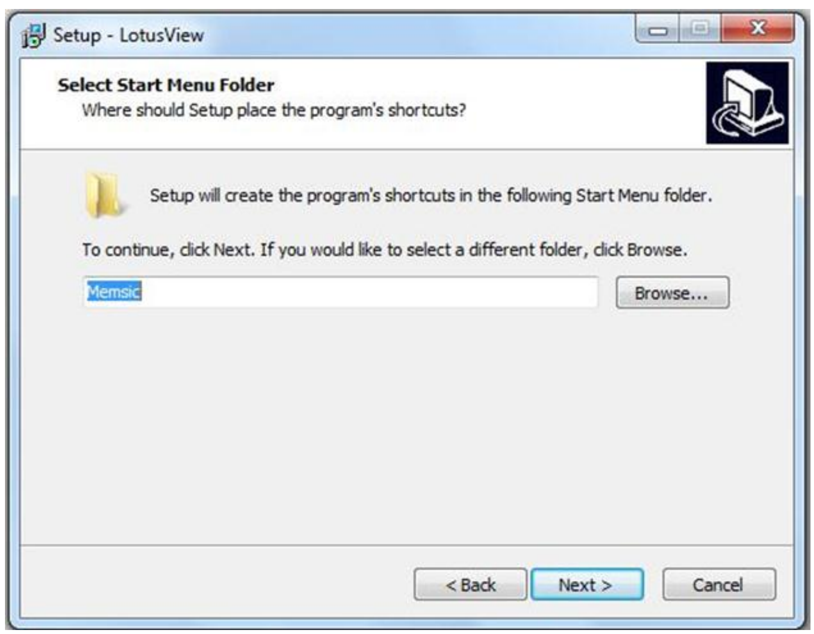

Figure 90 Selecting start menu folder for LotusView

6. Select all available installation tasks and click Next> (see figure 91 and 92).

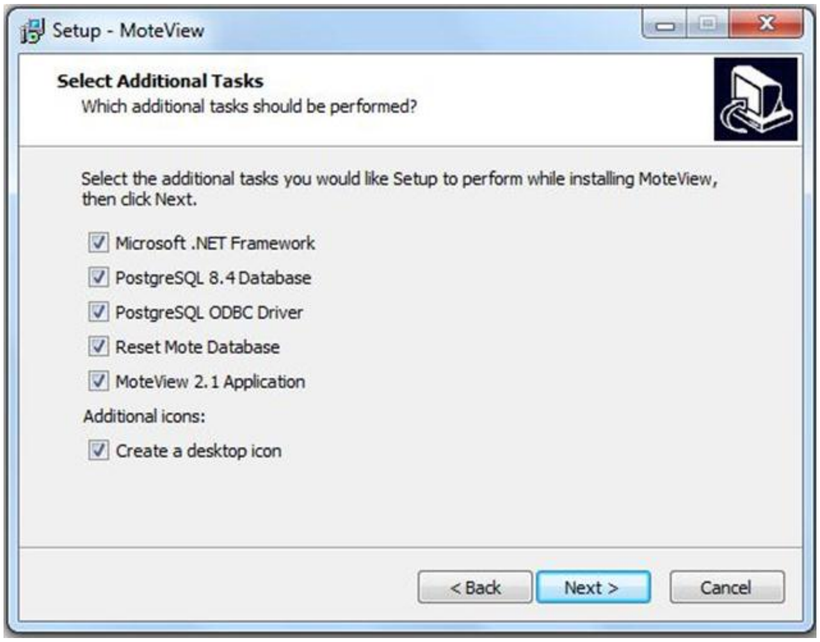

Figure 91 Selecting additional tasks for MoteView

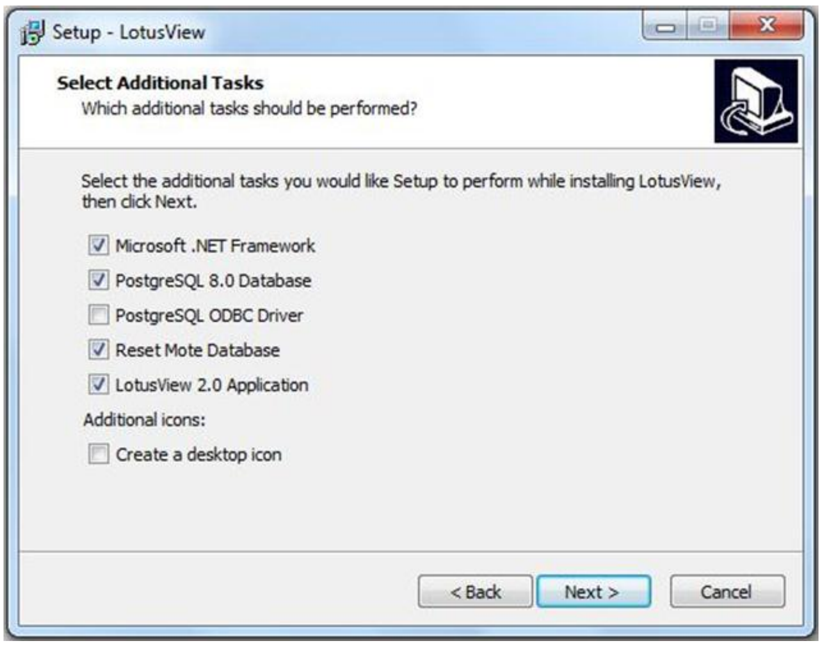

Figure 92 Selecting additional tasks for LotusView

7. Confirm your selections and click Install (see figure 93 and 94).

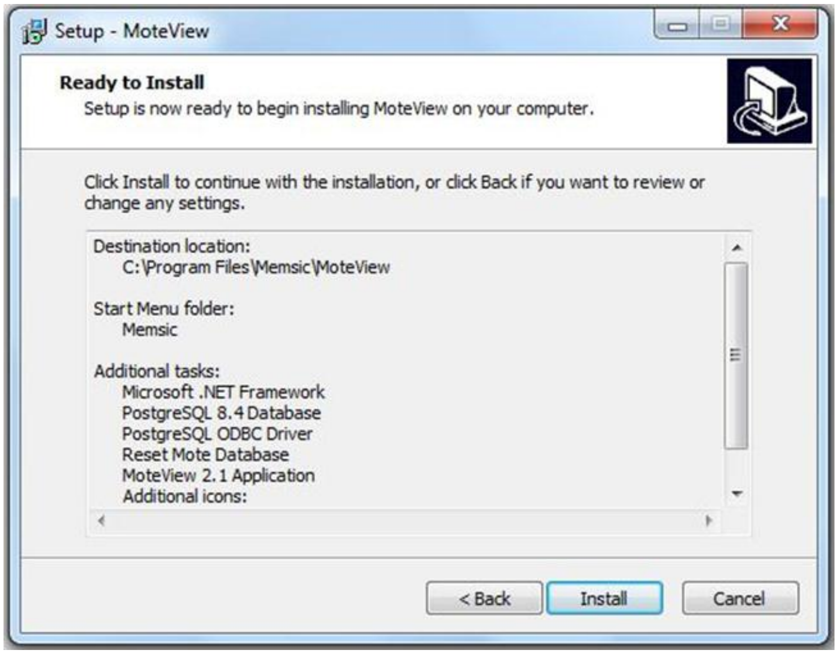

Figure 93 Confirm selections for MoteView

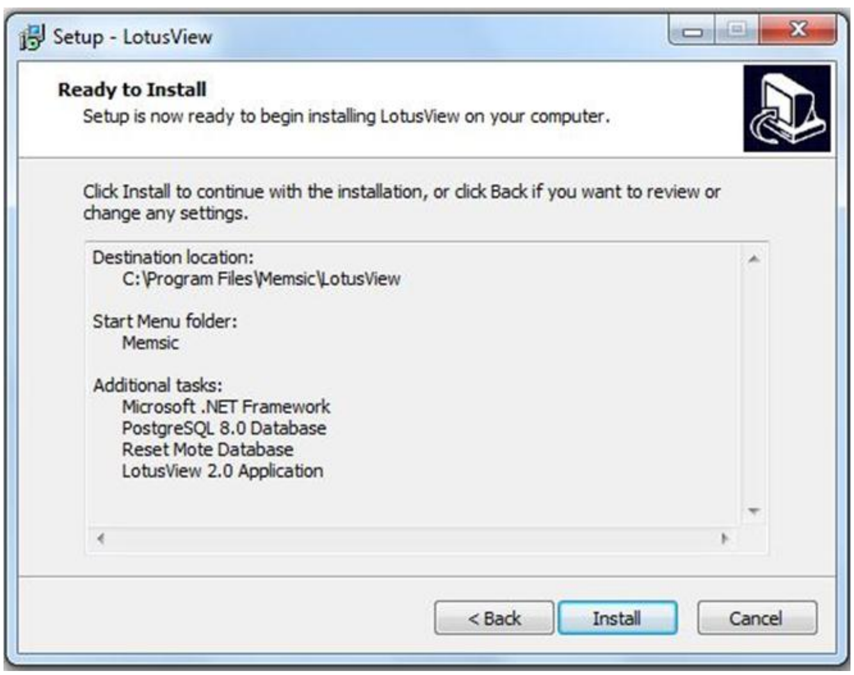

Figure 94 Confirm selections for LotusView

8. When the Setup Wizard has finished it will ask if you want to start the application. You may start it now, but in some cases it may ask you to restart your computer first.

Install the drivers

We need to install the drivers for USB base station for IRIS and LOTUS motes, when we connect the MIB520 or LOTUS mote USB base station to the available USB port on the PC, a pop up window will come out shows "Found new hardware", asking to install the driver. So we need to choose "Install from a list or specific location", then browse to the USB Drivers folder of MEMSIC CDs. Follow the instruction to finish the rest of driver installation.

Program Sensor Nodes

In this section we will describe how to program our sensor nodes for IRIS and LOTUS wireless motes.

Program IRIS Nodes

We can program our IRIS nodes as following:

- Open MoteView application
- Press the Program Mote button () on the MoteView toolbar to spawn the Mote-Config GUI as shown in Figure 95.
- Click on Settings > Interface Board... to select the correct gateway and port settings. The low numbered port is used for programming.

- Press the Select button to open a file browser and navigate to the folder that corresponds to your Mote processor/radio board, radio frequency and sensor board type. Normally, it is located in C > Program Files > Memsic > MoteView > XMesh > iris.

After an application has been selected, we can see the default parameters programmed into the application as shown in Figure 96.

- Press the Program button to download the selected firmware and configuration into the mote.

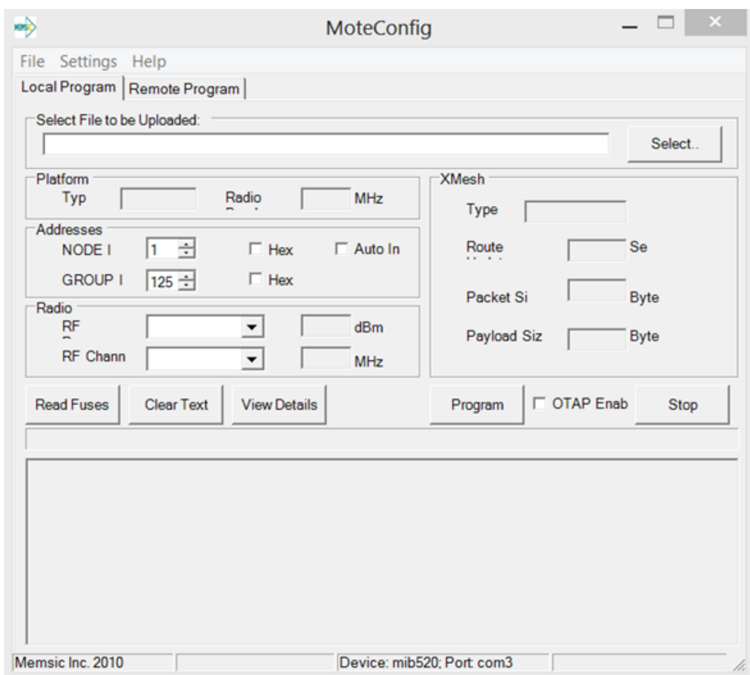

Figure 95 MoteConfig Application GUI

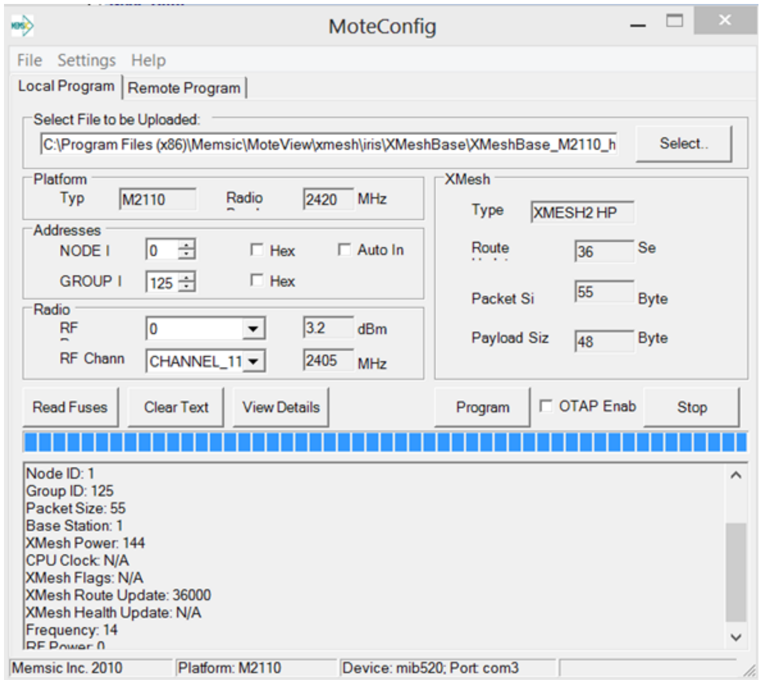

Figure 96 IRIS Node Programming

Program LOTUS Nodes

There is no significant difference between IRIS nodes programing and LOTUS nodes programing s we will see in the following steps:

- Open LotusView application
- Press the Program Mote button () on the LotusView toolbar to spawn the MoteConfig GUI as shown in Figure 97.
- Press the Select button to open a file browser and navigate to the folder that corresponds to your Mote processor/radio board, radio frequency and sensor board type. Normally, it is located in C > Program Files > Memsic > LotusView > XMesh > Lotus.

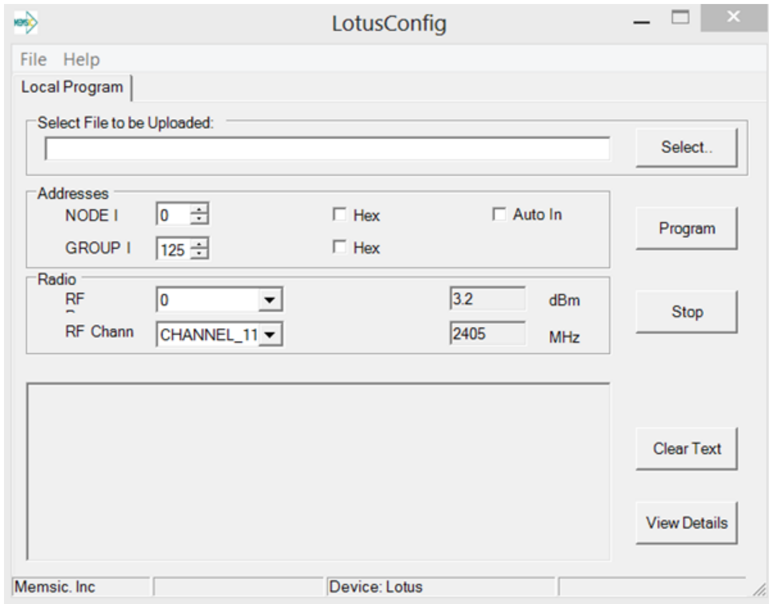

Figure 97 LotusConfig Application GUI

After an application has been selected, we can see the default parameters programmed into the application as shown in Figure 98.

- Press the Program button to download the selected firmware and configuration into the mote.
- Connect the LOTUS board to the PC and press OK.

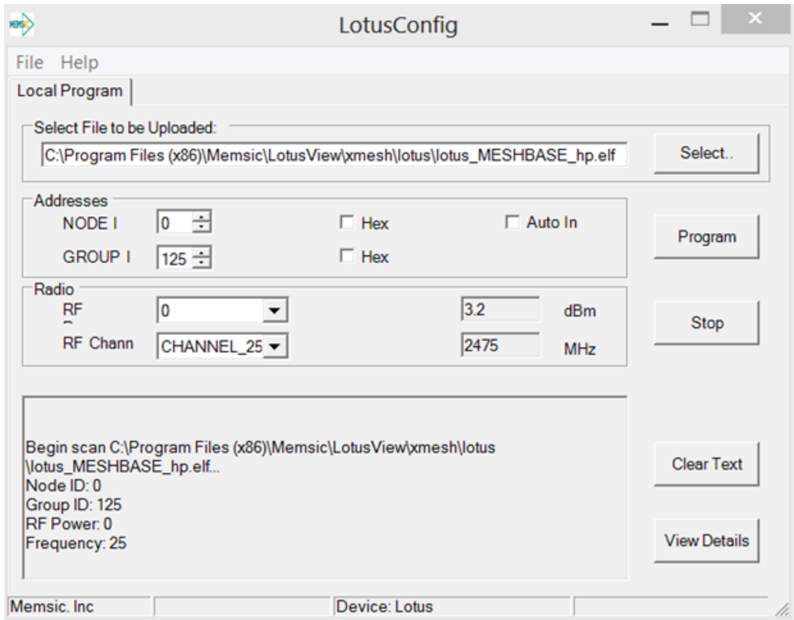

Figure 98 LOTUS Node Programming

Configure the Settings

When we finish the applications installation and nodes programming, we need to configure those applications properly to start collecting data from the sensor network.

MoteView Configuration

In order to configure MoteView properly, we have to follow these steps:

- Open MoteView application
- Click on the Connect to WSN icon . The following Figure 99 is the pop-up window.
- Check on acquire live data in the Mode tab and local as acquisition type, then click on Next >>.

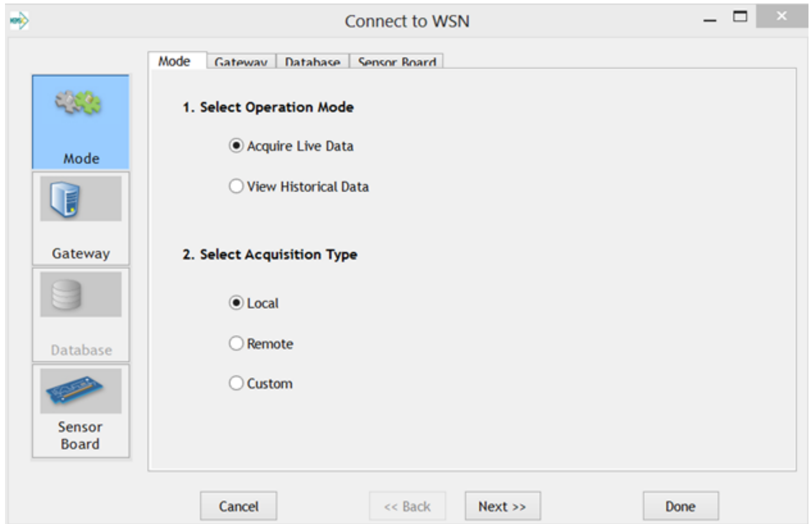

Figure 99 MoteView Mode Configurations

- In the Gateway tab, select MIB520 from interface board, the higher of the 2 COM ports as serial port, and select 57600 as baud rate as shown in figure 100, then click on Next >>.

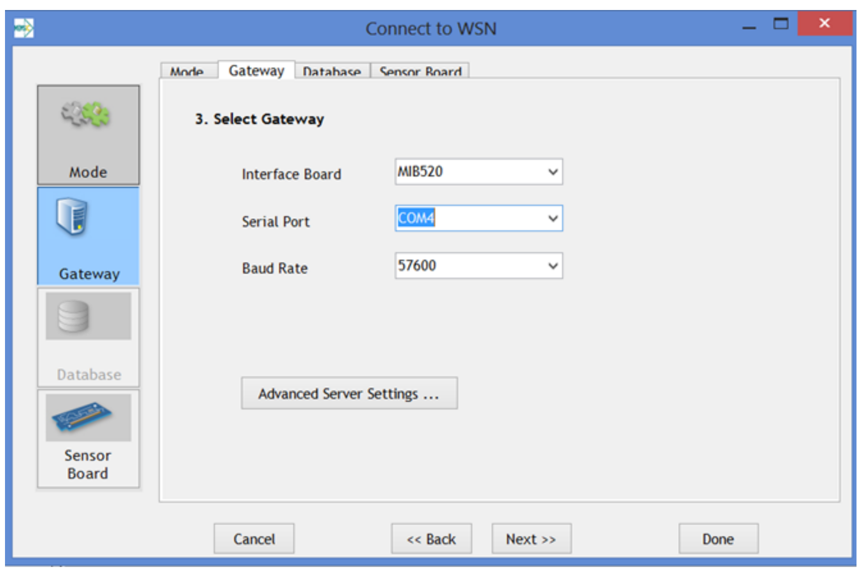

Figure 100 MoteView Gateway Configurations

- In the Sensor Board tab, choose the XMesh Application Name that matches the firmware programmed into the Mote from Application Name dropdown which is XMDA100 for our work (see figure 101). Finally, click on Done.

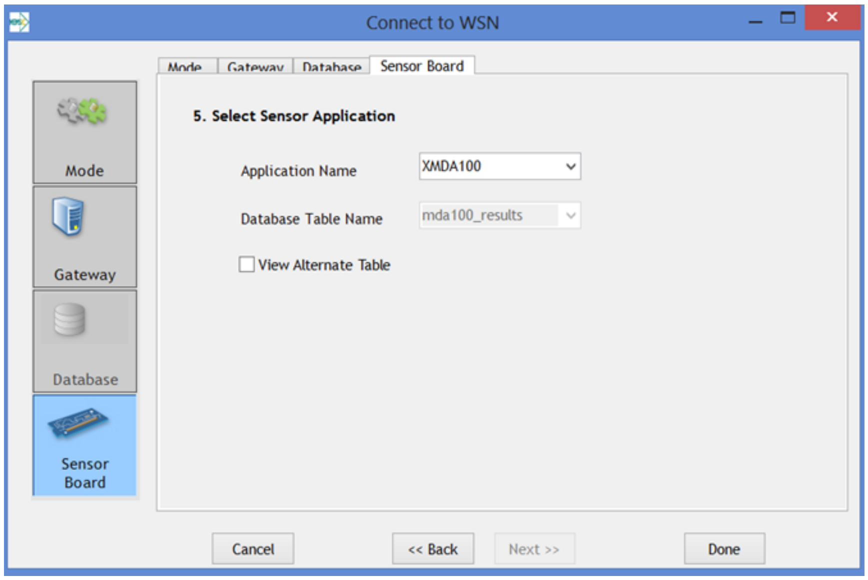

Figure 101 MoteView Sensor Board Configurations

LotusView Configuration

In this section we will describe how to configure LotusView to start collecting data from the LOTUS sensors.

- Open LotusView application

- Click on the Connect to WSN icon . The following Figure 102 is the pop-up window.

- From the Mode tab, check on Acquire Live Data as operation mode and Local as acquisition type and click on Next >>.

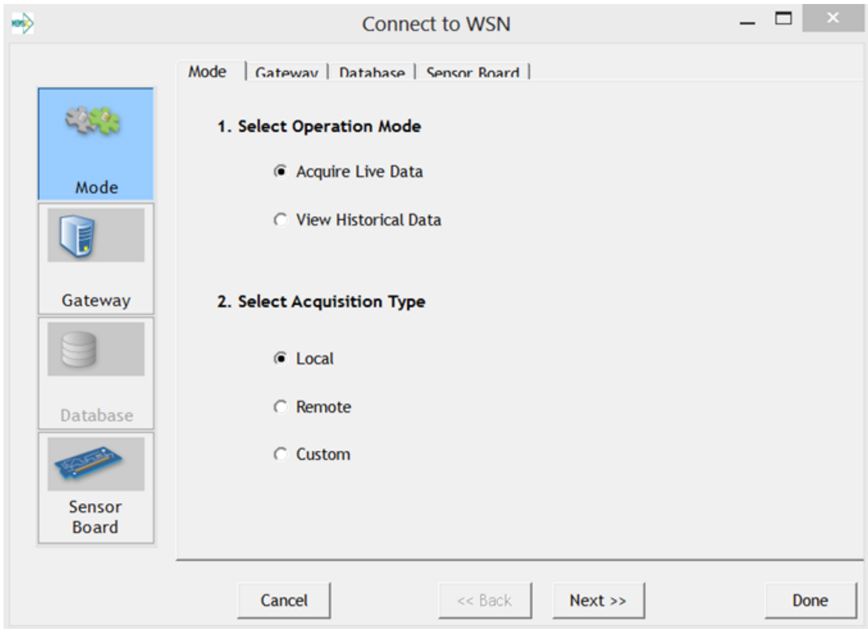

Figure 102 LotusView Mode Configurations

- From the Gateway tab, specify the Interface Board type and USB Port (see figure 103), click on Next >>.

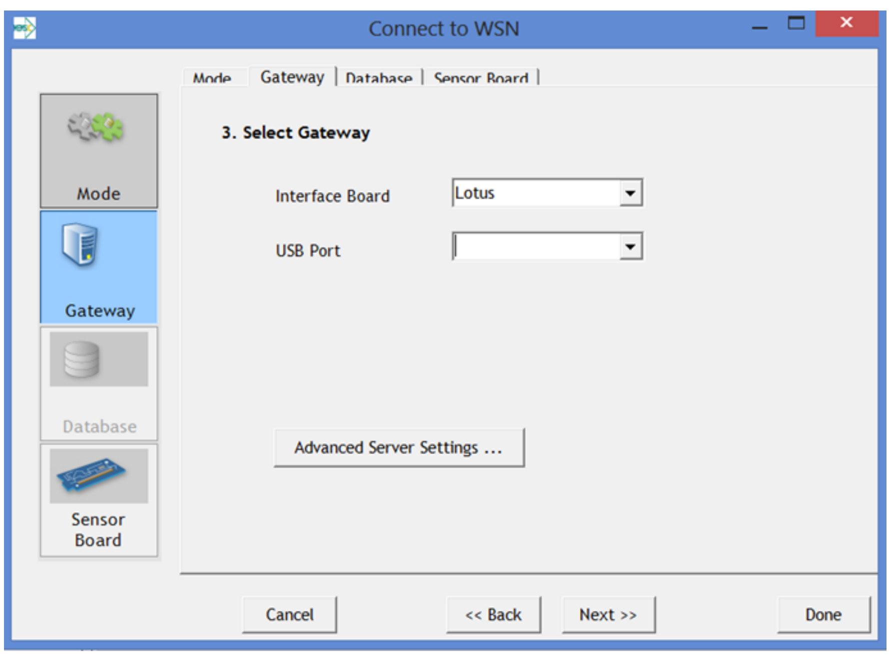

Figure 103 LotusView Gateway Configurations

- In the Sensor Board tab, choose the XMesh Application Name that matches the firmware programmed into the Mote from Application Name dropdown which is XMDA100 for our work (see figure 104). Finally, click on Done.

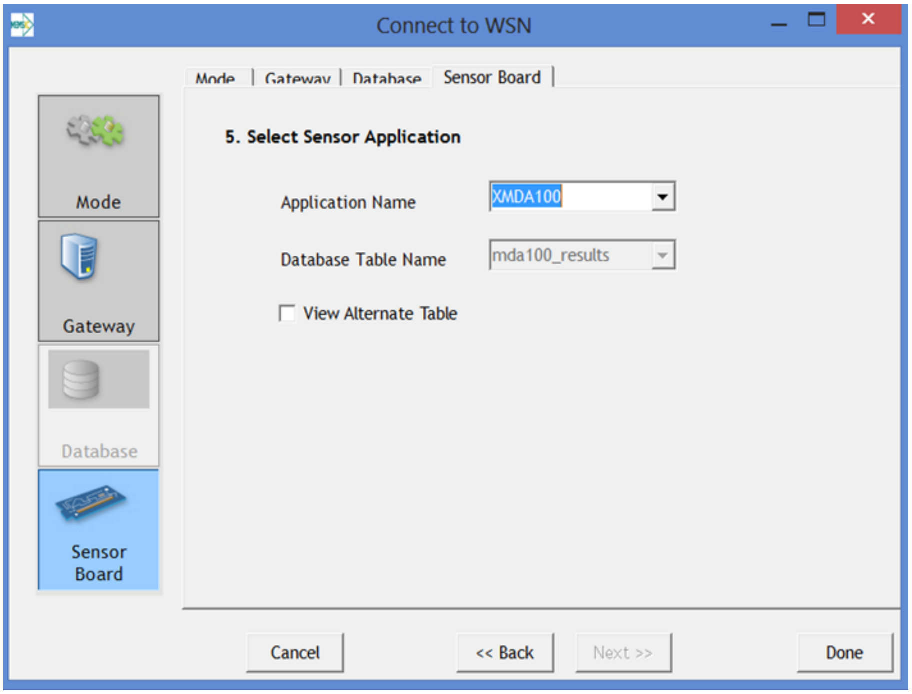

Figure 104 LotusView Sensor Board Configurations

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